IMPACTS OF CHLORINE USE ON ENVIRONMENTAL AND PUBLIC HEALTH

(A Science Report To Governor John Engler)

Prepared by
Michigan Environmental Science Board
Chlorine Panel

MICHIGAN ENVIRONMENTAL SCIENCE BOARD
LEWIS CASS BUILDING
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JUNE 1994

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June 1994

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PREFACE

Michigan Environmental Science Board

The Michigan Environmental Science Board (MESB) was created by Governor John Engler by Executive Order 1992-19 on August 6, 1992. The MESB is charged with advising the Governor, the Natural Resources Commission, the Michigan Department of Natural Resources and other state agencies, as directed by the Governor, on matters affecting the protection and management of Michigan's environment and natural resources. The MESB consists of nine individuals and an executive director, appointed by the Governor, who have expertise in one or more of the following areas: engineering, ecological sciences, economics, chemistry, physics, biological sciences, human medicine, statistics, risk assessment, geology and other disciplines as necessary. Upon the request of the Governor to review a particular issue, a panel, consisting of MESB members with relevant expertise, is convened to evaluate and provide recommendations on the issue.

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MAJOR FINDINGS AND CONCLUSIONS

The International Joint Commission's (IJC) Seventh Biennial Report on Great Lakes Water Quality, released less than three months ago, recommended that the governments of Canada and the United States "*...consult with industry and other interests to develop timetables to sunset the use of chlorine and chlorine-containing compounds as industrial feedstocks and examine the means of reducing and eliminating other uses, recognizing that socio-economic considerations must be taken into account in developing the strategies and timetables*". This statement, when considered alone does not appear to be as inflammatory as the issue has become at this time. The controversy surrounding the proposal for regulatory elimination (sunsetting) of chlorine use has been heightened by the language used within the debate and the vagueness of the above statement. Those in support of the sunsetting of chlorine have often used as examples the toxic effects of known, environmentally persistent, bioaccumulative chlorinated compounds. An undefined timetable and an inability to know which chlorine-containing compounds and their uses are involved in the proposed ban provide fertile ground for the imaginations of proponents and antagonists. These factors and the vast economic resources involved in chlorine use have fueled much concern and discussion.

On November 18, 1993, the Michigan Environmental Science Board (MESB) was charged by Governor John Engler to evaluate the scientific basis for the IJC's recommendations on chlorine and chlorinated compounds and to evaluate whether Michigan's body of regulations affecting the use of chlorine and chlorinated compounds adequately protect Michigan's citizens' health, its environment and its Great Lakes.

A Panel, composed of six MESB members, was convened on November 30, 1993 to begin the project. The investigation consisted of the accumulation and evaluation of peer-reviewed and some non-peer-reviewed literature and data on the subject. In addition, verbal and written statements from experts, industry specialists, environmental organizations, state governmental agencies and concerned citizens were considered. Major findings and conclusions of the MESB Chlorine Panel are summarized below.

♦ The known toxicity of certain chlorinated compounds, particularly those exhibiting persistence, and the possibility that *unknown* products of similar toxic potential are now reaching the environment, or may do so in the future, makes it necessary to evaluate current and future uses of chlorine and chlorinated compounds. Discussions, similar to those called for by the IJC, should take place among industry, government and public interest groups to examine the risks and benefits of the chlorinated products in use. Included in these discussions should be the consideration of safety and effectiveness of possible alternatives to chlorine-containing compounds and processes. The timetable for these discussions and the actions resulting from them should be reflective of sound science, the current importance of chlorine to society and the lack of alternatives of known safety and effectiveness. It would seem reasonable that known and suspected harmful chlorinated compounds or processes would be eliminated over a period of 30 years or less using a priority system addressing health, economic and other societal factors.

♦ The addition of chlorine atoms to an organic molecule usually increases its solubility in lipid and often increases the length of time it is present in the environment. The combination of lipid solubility and environmental persistence can result in accumulation of organic compounds in the food chain. In general, a toxic compound which is bioaccumulating in the environment, particularly in the food chain represents a greater threat to environmental and public health when compared to the threat from an equally toxic compound that does not bioaccumulate.

♦ The grouping of chemical substances for regulatory purposes on the basis of physical, chemical and biological characteristics is scientifically defensible whereas consideration of a single property (e.g., contains chlorine) alone is likely to be inadequate for the intended purpose. Thus, persistent toxic chlorinated and non-chlorinated compounds released to the environment can be treated as a group for the purpose of regulatory control. Toxic compounds currently known to be persistent and bioaccumulative in the

environment should be vigorously controlled. Procedures to adequately detect these and the many unknown compounds either individually or as mixtures should be implemented.

♦ Scientific evidence indicates that all chlorine-containing organic compounds do not have similar potential to produce deleterious effects in humans and in the environment.

♦ There is *insufficient* scientific evidence to indicate that the mere presence of non-persistent chlorinated compounds in the environment is producing an environmental or public health threat. Likewise, *insufficient* evidence does not prove lack of potential for harm.

♦ Some non-persistent chlorinated compounds including certain volatile organic solvents can produce toxic effects at high exposures that may occur with accidents or in occupational settings. The ability of these types of chemical substances to produce long lasting health effects such as cancer, neurological damage or reproductive deficits as a result of lower environmental exposures is generally not convincing at this time. Sunsetting of this group of chemical compounds should not occur precipitously.

♦ New chlorinated and non-chlorinated products and by-products of industrial processes should be evaluated for their toxicity, persistence and bioconcentration potential prior to being released into commerce and the environment. The toxicity testing applied to products, emissions and effluents from new industrial processes should be sufficiently sensitive to detect adverse effects that might occur in wildlife, domestic animals and humans at concentrations known or reasonably estimated to occur in the environment. The testing paradigm applied should be capable of detecting several types of non-lethal toxic effects including those leading to neurotoxicity, hormone modulation resulting in reproductive and developmental toxicities and immunotoxicity. If the testing paradigm now being used cannot detect the toxic effects of chemical substances currently considered to be particularly hazardous (e.g., 2,3,7,8-TCDD) when they are present in concentrations above scientifically sound regulatory standards, it should be considered inadequate for protection of public and environmental health and replaced with a more appropriate protocol.

♦ Previously installed industrial processes for which there is inadequate information regarding the identity and/or toxicity of the by-products released to the environment should be subjected to an adequate toxicity testing paradigm. This should be done to provide data indicating the potential of released unknown by-products to produce harm to the environment and public health, and sufficient information to allow a risk/benefit evaluation to be made.

♦ The replacement of chlorine and potentially toxic chlorinated compounds in industrial processes with equally beneficial alternative chemical compounds and processes will require toxicity testing for a new set of products and by-products. Studies involving the use of intact animals, cells and isolated tissues derived from animals will be required. The efficacy of the tests used to evaluate the safety of alternative products and the associated by-products should be equivalent to tests required for chlorine-containing products and by-products.

♦ The current body of chlorine and chlorinated compound-related regulations operable in Michigan may be considered reasonably adequate to protect human health, the environment and the Great Lakes but should be (a) periodically reviewed and upgraded in terms of requiring more appropriate monitoring and evaluation requirements consistent with new environmental and human health data regarding chlorinated compounds and their potential substitutes, (b) ensured of sufficient human and financial resources to allow for aggressive and effective enforcement and (c) supplemented with a monitoring program capable of establishing and tracking changing trends in contaminants impacting both the abiotic and biotic environments.

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INTRODUCTION

The Michigan Environmental Science Board (MESB) was created by Governor John Engler by Executive Order 1992-19 on August 6, 1992. The MESB is charged with advising the Governor, the Natural Resources Commission, the Michigan Department of Natural Resources and other state agencies, as directed by the Governor, on matters affecting the protection and management of Michigan's environment and natural resources. The MESB consists of an executive director and nine individuals appointed by the Governor. Each member has expertise in one or more of the following areas: engineering, ecological sciences, economics, chemistry, physics, toxicology and biological sciences, human medicine, statistics, risk assessment, geology and other disciplines as necessary. Upon the request of the Governor to review a particular issue, a Panel, consisting of MESB members with relevant expertise, is convened to evaluate and provide recommendations on the issue.

On November 18, 1993, the MESB was charged by Governor Engler (Engler, 1993) to evaluate the uses of and concerns about chlorine and chlorinated compounds in Michigan in order to provide guidance to policy-makers on these issues (see Appendix I). On November 30, 1993, a Chlorine Panel, composed of six MESB members, was convened to begin the investigation. The investigation consisted of the accumulation and evaluation of peer-reviewed and some non-peer-reviewed literature and data on the subject. In addition, verbal and written testimony from experts, industry specialists, state regulatory agencies, environmental organizations and concerned citizens were considered at five meetings (Harrison, 1994a; 1994b; 1994c; 1994d; 1993). The report was prepared by the Panel members with each individual assigned a specific topic or topics to address. The investigation lasted for a period of six months.

The report addresses two specific directives from the Governor:

1. Evaluate the scientific basis for the International Joint Commission (IJC) recommendations on chlorine and chlorinated compounds; and

2. Based on the evaluation of the IJC recommendations, evaluate whether Michigan's body of regulations affecting the use of chlorine and chlorinated compounds adequately protect Michigan's citizens' health, its environment and its Great Lakes.

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DIRECTIVE #1. Evaluate the scientific basis for the International Joint Commission recommendations on chlorine and chlorinated compounds.

Introduction

The IJC's Seventh Biennial Report on Great Lakes Water Quality, released less than three months ago, recommended that the governments of Canada and the United States "*...consult with industry and other interests to develop timetables to sunset the use of chlorine and chlorine-containing compounds as industrial feedstocks and examine the means of reducing and eliminating other uses, recognizing that socio-economic considerations must be taken into account in developing the strategies and timetables*" (IJC, 1994). This statement, when considered alone does not appear to be as inflammatory as the issue has become at this time. The controversy surrounding the proposal for regulatory elimination (sunsetting) of chlorine use has been heightened by the language used within the debate and the vagueness of the above statement. Those in support of the sunsetting of chlorine have often used as examples the toxic effects of known, environmentally persistent, bioaccumulative chlorinated compounds. They provide the view that urgency is needed to preserve present levels of public and environmental health. An undefined timetable and an inability to know which chlorine-containing compounds and their uses are involved in the proposed ban provide fertile ground for the imaginations of proponents and antagonists. These factors and the vast economic resources involved in chlorine use have fueled much concern and discussion.

The MESB Chlorine Panel has been asked to report on the validity of the science-based arguments used to support the proposal to eliminate the use of chlorine and chlorinated compounds and to comment on the ability of present regulations to protect public and environmental health from harm due to these materials. During the course of the investigation, a large amount of scientific and non-scientific information has been collected and assimilated by MESB Chlorine Panel members. The Panel has found that the issue is characterized by information so vast, unknowns so numerable, and boundaries so undefinable that even a large, conscientious effort to report on this issue can be considered inadequate. Nevertheless, the Panel accepted the challenge created by this issue and the following report can be considered a consensus scientific opinion of the members of the MESB Chlorine Panel with concurrence from the full MESB. The U.S. Environmental Protection Agency (USEPA) will be also addressing the chlorine issue (Perciasepe, 1994) and its findings should extend those reported here.

It should be understood that the MESB Chlorine Panel considers the Sixth and Seventh IJC Biennial Reports as policy documents rather than scientific reports. It is neither the goal nor desire of the Panel to address state or federal policy implications of the IJC's recommendation to sunset chlorine use. The response provided to this Directive purposefully attempts to address only the scientific basis implicit or inferred in the policy recommendation put forward by the IJC. As such, the information presented can serve to provide only one of several bases of information which will undoubtedly be needed before any final policy decision can be made regarding this very complex environmental and

public health issue.

Background for IJC Recommendation

Article II of the 1978 Great Lakes Water Quality Agreement between the U.S. and Canada (IJC, 1989) states that the policy of the two countries is to prohibit the discharge of toxic substances in toxic amounts and to virtually eliminate the discharge of any or all persistent toxic substances into the Great Lakes. In 1992, the IJC (1992b) concluded that despite the Agreement requirement to virtually eliminate the input of persistent toxic substances to the Great Lakes basin, neither virtual elimination nor zero discharge had been achieved for any persistent toxic substance. As a consequence, the IJC indicated that in order to achieve the provisions of the Agreement, "*sunsetting*" - a comprehensive process to restrict, phase out and eventually ban the manufacture, generation, use, transport, storage, discharge and disposal of persistent toxic substances - would be needed.

Article I of the 1978 Great Lakes Water Quality Agreement (IJC, 1989) defines a "*toxic substance*" as one which can cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological or reproductive malfunctions or physical deformities in any organism or its offspring, or which can become poisonous after concentration in the food chain, or in combination with other substances. Annex 12 to the Agreement defines a "*persistent toxic substance*" as any toxic substance with a half-life in water of greater than eight weeks. In its Sixth Biennial Report, the IJC (1992b) recommended that the definition of "*persistent toxic substance*" be enlarged to encompass all toxic substances with a half-life in any medium - water, air, sediment, soil or biota - of greater than eight weeks, as well as those substances that bioaccumulate in the tissue of living organisms.

The IJC's Sixth Biennial Report (IJC, 1992b) focused its discussion and recommendations on 11 persistent toxic substances which are known to cause injury. Of the 11 identified persistent toxic substances, eight are chlorinated compounds. Sunsetting was recommended for six of the eight identified chlorinated persistent toxic substances (polychlorinated biphenyl - PCB, dichlorodiphenyltrichloroethane - DDT, dieldrin, toxaphene, mirex and hexachlorobenzene) and changes were called for in production processes and industrial feedstock chemicals in order to avoid by-product production of hexachlorobenzene and two additional chlorinated persistent toxic substances, dioxins and furans.

The IJC's recommendations for the 11 (eight chlorinated and three non-chlorinated) persistent toxic substances were based on two criteria: (1) confirmed cause and effect evidence and (2) the amount and consistency of evidence which, if taken together across a wide range of circumstances and/or toxic substances are judged sufficient to indicate the reality or a strong probability of a linkage between certain substances or class of substances and injury or the likelihood of injury, a conclusion of causal relationship can be made. This latter criterion, termed "*weight of evidence*", was also recommended by the IJC in the Sixth Biennial Report as an approach to be adopted by the U.S. and Canada to identify and virtually eliminate persistent toxic substances.

The IJC (1992b) indicated that the sunsetting of the persistent toxic substances also may require consideration of the manufacturing process and products associated with a chemical substance's production and use, as well as of the chemical substance itself, and realistic yet finite time frames to achieve the virtual elimination of the persistent toxic substance. This approach raised the question as to whether the use of chlorine, the common precursor for the production of [persistent and nonpersistent] chlorinated organic substances, should be sunset.

The IJC (1992b) stated that approximately half of the 362 synthethically-produced chemical compounds known to be present in the water, sediment and/or biota of the Great Lakes basin ecosystem were chlorinated organic substances. In addition, the IJC indicated that "...there are other chlorinated organic substances entering the environment that have not yet been separately identified. Even though many of these substances have not been proven to be individually toxic, it is likely that many of these chemical compounds, because of their chemical characteristics, will be identified as persistent toxics and hence substances to be virtually eliminated." The IJC continued by stating that "there is a growing body of evidence that ... [the chlorinated] compounds are at best foreign to maintaining ecosystem integrity and quite probably persistent, toxic and harmful to health. [The compounds] ... are produced in conjunction with proven persistent toxic substances [and,] in practice, the mix and exact nature of these ... compounds cannot be precisely predicted or controlled in production processes."

The IJC (1992b) concluded that "...it [would be] prudent, sensible and necessary to treat ... [the chlorinated compounds] as a class rather than a series of isolated individual chemicals;" and that because chlorine is the common precursor in the diverse set of industrial processes that produce this class of substances, "...the use of chlorine and its compounds should be avoided in the manufacturing process."

Based on the above, the IJC recommended in its Sixth Biennial Report (IJC, 1992b) that the U.S. and Canada, "*... in consultation with industry and other affected interests, develop timetables to sunset the use of chlorine and chlorine-containing compounds as industrial feedstock and that the means of reducing or eliminating other uses be examined.*" The IJC's conclusions and recommendations regarding chlorine were reaffirmed in its Seventh Biennial Report (IJC, 1994).

In the discussions that follow, the MESB Chlorine Panel has attempted to evaluate the basis and logic for the IJC recommendation on chlorine and chlorinated compounds from a variety of scientific perspectives.

Chlorine Production and Use

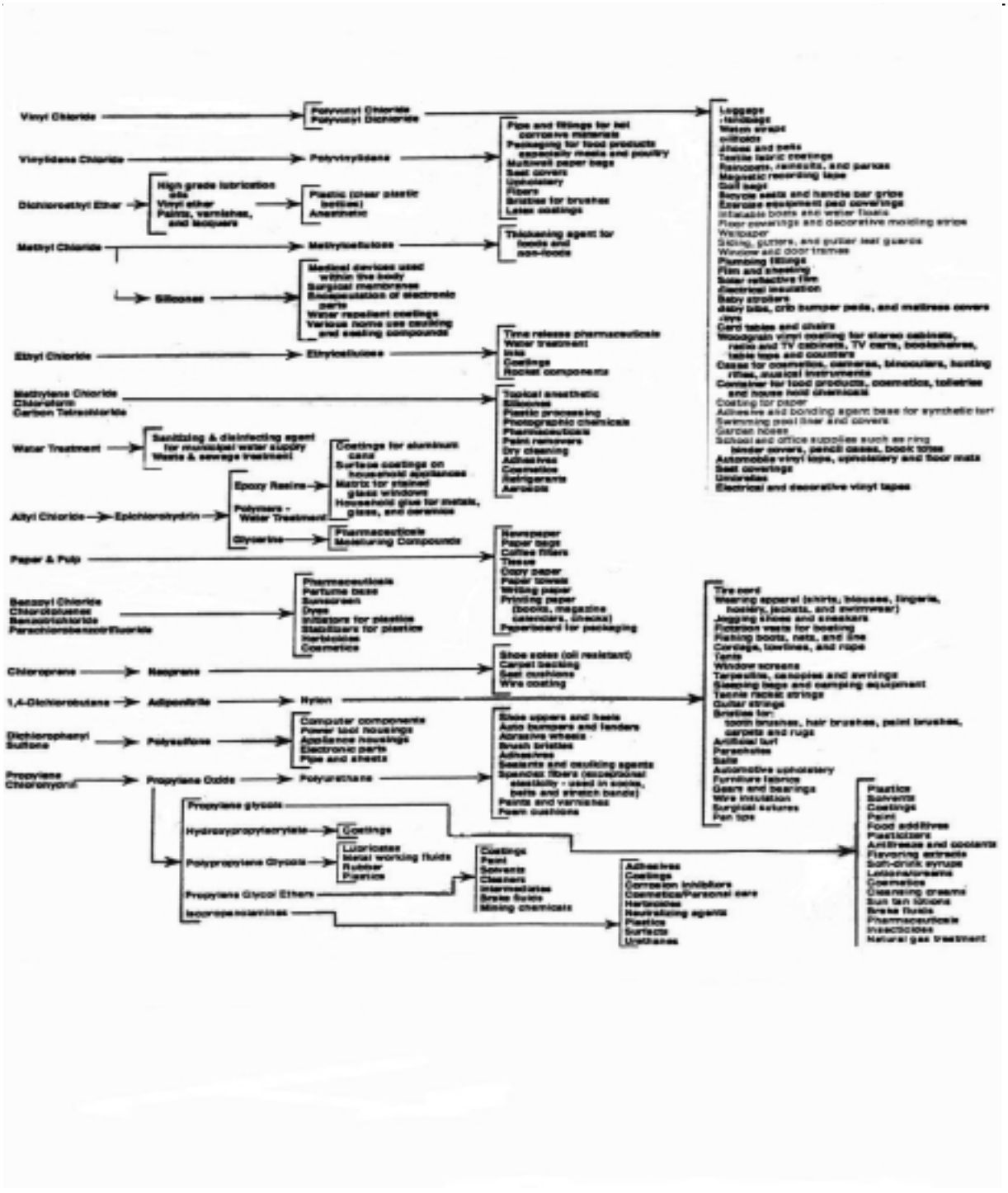
Chlorine plays a role in virtually every sector of the economy. Elemental chlorine is used to disinfect water and to bleach paper pulp. Chlorinated compounds are used in the production of plastics, cleaning and disinfecting materials, pharmaceuticals, pesticides, and many other products (see Table 1; Figure 1).

Table 1. Commonly used products containing chlorinated compounds.[1]

Adhesives	Ring binder covers, pencil cases, book totes
Aerosols	Pacemaker batteries
Antifreeze & coolants	Paint removers
Artificial turf	Parachutes
Artificial turf adhesive & bonding agents	Pen tips
Automobile interior trim & padding	Pharmaceuticals
Automobile upholstery	Photographic chemicals
Baby strollers, cribs, crib pads & mattresses	Photographic film
Bandaids®	Pigments & dyes
Bicycle seats & handlebar grips	Pipe & fittings for corrosive materials
Boats	Plumbing fittings
Brake fluids	Raincoats, rain suits & parkas
Bristles for brushes	Refrigerants
Carpet backing	Rocket components
Coating for paper	Rocket propellants
Coatings for aluminum cans	Sails
Cosmetics	Seat cushions
Degreasers	Shoes
Dental cements	Siding, gutters & leaf guards
Deodorant	Silicones
Dry cleaning	Sleeping bags
Electrical insulation	Soft-drink syrups
Erasers	Soil-resistant shoe soles
Exercise equipment padding	Solar reflectors
Fireworks	Soldering fluxes
Flame retardants	Spot remover
Floor coverings & decorative molding	Sunscreen
Flooring	Surface coating for household appliances
Flotation safety devices	Surgical sutures
Food flavoring	Swimming pool liners & covers
Food packaging (especially meat/poultry)	Synthetic caffeine
Furniture upholstery	Table salt
Garden hoses	Tarps, canopies & awnings
Gears & bearings	Tennis racket strings
Golf bags	Tents
Guitar strings	Textile fabrics
Hair care products	Tire cord
Handbags	Topical anesthetic
Household glue for metals, glass & ceramics	Toys
Inflatable boats & water floats	Umbrellas
Inks	Upholstery & seat covers
Insecticides	Wallpaper
Jogging shoes & sneakers	Watch straps
Latex coatings	Window & door frames
Luggage	Window screens

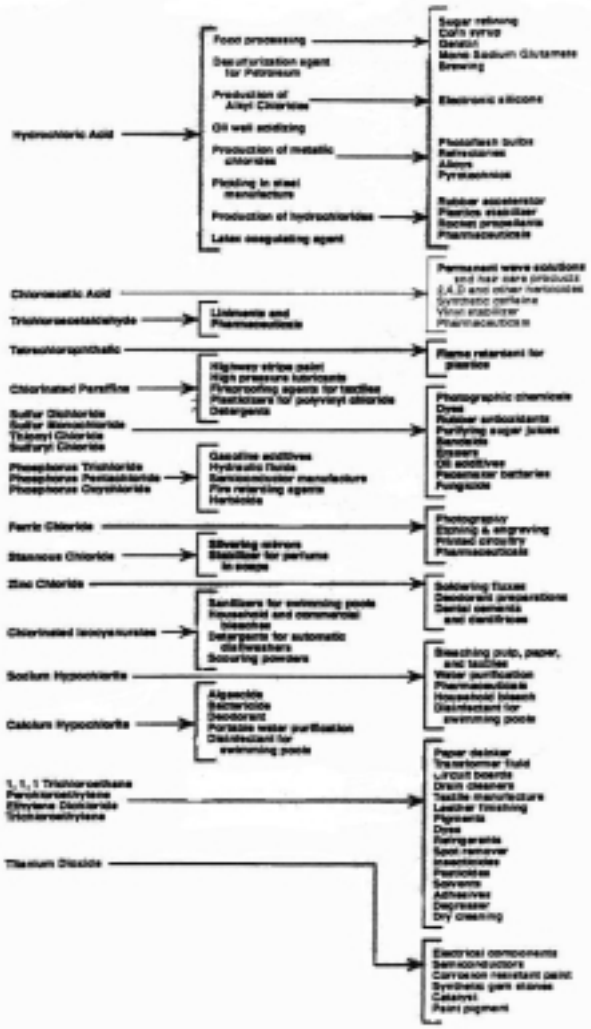
1. From Michigan Chemical Council, 1994b.

Figure 1. Chlorine dependent products.



1. Source: Dow Chemical Company, 1992.

Figure 1. Chlorine dependent products (continued).



1. Source: Dow Chemical Company, 1992.

In 1990, total world consumption of elemental chlorine was approximately 37.4 million tons (Ehrenfeld *et al*., 1993). The U.S. was the world's largest user, consuming 11 million metric tons. The U.S. also produced 10.7 million metric tons of elemental chlorine (USDC 1992). According to the Chlorine Institute (1994), 49 plants in the U.S. produce chlorine for commercial sale, seven of which operate in the Great Lakes basin. In 1991 there was one plant producing elemental chlorine in Michigan (USDC, 1993); currently, however, there are none (Michigan Chemical Council, 1994a). In addition, 153 polyvinyl chloride resin fabrication plants operate in Michigan (CMA, 1993).

It is estimated that over 15,000 synthetically-produced chlorinated compounds are currently in commerce (Ehrenfeld *et al*., 1993). In addition, over 2,000 naturally produced chlorinated compounds exist in nature (Gribble, In press; 1994; 1992; Grimvall, 1993; Asplund and Grimvall, 1991).

Chlorine Chemistry and Fate

The element chlorine has two key physicochemical properties. First is its strong electrophilic or oxidizing tendency. It is effective as an oxidant in diverse applications such as pulp bleaching and water disinfection. When chlorine is present in organic compounds, this effect tends to reduce reactivity, for example, by oxidation or biodegradation (Solomon *et al*., 1993). It imparts stability to certain pesticides and to organic solvents, such as the chlorinated ethylenes which would otherwise be highly flammable. This stability is also manifested as environmental persistence, which increases with increasing chlorination. Within a molecule, chlorine withdraws electrons; this effect imparts greater acidity in chlorophenolic substances such as pentachlorophenol (PCP).

Second is the relatively large size and mass of the chlorine atom. The substitution of a chlorine atom for a hydrogen atom in an organic molecule increases molar volume by about 21 cm^3/mol, which is similar to the effect of adding a methyl (CH_3) group. This results in a larger molecule which has a reduced vapor pressure, an increased boiling point, and a reduced solubility in water - by about a factor of four to six per mole chlorine atoms. This trend is incremental and may be slight for one chlorine atom, becoming larger as additional chlorine atoms are added. The tendency to partition from water into organic phases increases as a result of chlorination. This is usually expressed as an increase in hydrophobicity as indicated by K_{ow}, the octanol-water partition coefficient. The partitioning coefficient is a measure of whether a compound is more soluble in water or octanol. Addition of chlorine increases the tendency to bioconcentrate since the bioconcentration mechanism is basically one of water-to-lipid partitioning. With chlorination, there is usually also an increase in acute lethality as expressed, for example, by the lethal concentration in water to 50% of a fish species (LC_{50}). If lethality or other adverse effects develop at a particular concentration within the organism, then a more hydrophobic substance will achieve this residue level at a lower concentration in water, because the partition coefficient from water to organism is larger. The toxicity, as indicated by a lower LC_{50}, increases. Substitution of chlorine for hydrogen therefore increases K_{ow}, increases partitioning to the organism and usually reduces the LC_{50},

rendering the substance more lethal (Solomon *et al*., 1993). These concepts hold true if the toxicity of a molecule is only controlled by the rate of movement to a target site in the body. In many if not most cases, this is an oversimplification of a very complex set of processes which act to control the biological activity of chemical compounds.

A third effect is that, in certain molecules, the placement of chlorine in *strategic* positions gives a structure which has a strong tendency to bind to certain biomolecules and thus manifest various biological effects. An example is the binding of coplanar PCBs and 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) to the Ah (aromatic hydrocarbon) receptor in the cell resulting in the induction of particular enzymes (Solomon *et al*., 1993). These specific effects often outweigh the importance of hydrophobicity imparted by the presence of a chlorine molecule.

According to Solomon *et al*. (1993), the substitution of chlorine for hydrogen *usually* produces an incremental effect on the physical properties of organic molecules, and the nature of these changes in properties and the resulting effects on environmental transport and transformation is *generally* understood and, to an extent, predictable. The effect of the chlorine atom on the biological activity of an organic compound is less predictable.

The chlorinated compounds which are of primary concern are those which have three key properties. First, they are persistent, i.e., they survive for many months or years in the environment, and have an opportunity to migrate considerable distances and may survive food chain transfer. The best indicator of this is an environmental half-life. The IJC uses a half-life of greater than eight weeks as a criterion to define persistence in water, air, sediment, soil and biota (IJC, 1992b). Second, they are highly bioaccumulative and develop high concentrations in aquatic organisms. The best indicators of bioconcentration are K_{ow} or solubility in water. Generally, compounds with K_{ow} lower than 2000 are not considered to have a high bioconcentration potential (corresponding approximately to a bioconcentration factor of 100). Third, they often display toxicity towards aquatic organisms such as fish (Solomon *et al*., 1993).

The chlorinated compounds which fall into all these categories are primarily the chlorinated aromatic compounds, i.e., the biphenyls, dioxins, dibenzofurans, benzenes, naphthalenes, phenols and chlorinated pesticides such as DDT. In addition, certain non-aromatic chlorinated compounds of alkane or cycloalkane structure are of concern, such as lindane, chlordane, and camphenes (toxaphene). In general, the higher the chlorine content, the greater is the level of concern. Highly chlorinated compounds, such as dioxins, dibenzofurans and polychlorinated phenols, have a greater potential for bioaccumulation and toxicity and are more persistent than their lesser chlorinated counterparts because these properties are enhanced by the presence of the additional chlorine atoms (Solomon *et al*., 1993).

Relative Persistency of Chlorinated Compounds

Characteristics of persistent toxic substances can be more clearly defined based on specific, measurable properties. Predictions of the relative persistency of chlorinated

organic chemical compounds can be made based upon the physical and chemical properties of those chemicals (Willes *et al*., 1993). The information that assists in making these predictions includes: (1) the solubility of the chemical substance in water and fat; (2) the extent and rate at which a chemical substance evaporates from soil or water into air; and (3) the degree and pattern of chlorination of the organic molecule. These characteristics have to be considered together because it is not always true that simply because a chemical substance has a certain chlorination pattern it is more persistent or bioaccumulative than another.

In general, persistent bioaccumulative chlorinated-compounds are less soluble in water (hydrophobic), more soluble in fat, evaporate slowly, and have a larger number of chlorine atoms attached to their carbon rings. The more soluble the compound is in octanol, the more soluble it is in fat and the higher will be its partitioning coefficient and its bioconcentration potential. Likewise, chlorinated compounds with a low partitioning coefficient have a lower solubility in lipid and lower bioconcentration potential.

For persistent hydrophobic substances, such as the dioxins, there is a better understanding of the fate and an ability to link loadings to concentrations. Degradation in the environment is slow and half-lives are measured in years. Sediments become the repository and may continue to release these substances long after loadings are reduced or eliminated (Solomon *et al*., 1993).

The fate of chlorophenols is less understood. The half-lives of these substances are measured in weeks and months. They do bioconcentrate but to a lesser degree than the dioxins. The partitioning coefficient of chlorophenols is much lower than that of dioxins.

AOX (absorbable organic halogens) consists of a mixture of high and low molecular mass organochlorines and comprise the bulk of discharged chlorinated compounds in complex effluents from processes in which chlorine is used (e.g., pulp and paper bleaching). AOX is measured by a method that determines the quantity of chlorine in a sample which is in a form that is retained on activated carbon. It is viewed as determining the total quantity of organically bound chlorine. EOX is extractable organic halogen (that which is extracted with a non-polar solvent such as hexane or heptane). Substances which are extracted are hydrophobic and have a large partitioning coefficient. The EOX test typically gives a concentration of a few percent of the AOX value (Axegard, 1986b; Earl and Reeves, 1989). This indicates that most of the AOX material is not hydrophobic. It is likely that this material does not bioconcentrate and that its toxic effects are restricted to physical interference such as alterations of biological membranes.

Environmental Studies

There are certain persistent toxic chlorinated and non-chlorinated substances within the Great Lakes environment that have created ecosystem, community, population, and organism level effects. Evidence from monitoring and research conducted at these levels indicates that this problem has been and is being addressed on a continuous basis.

Ecosystem Effects. Most of the published studies focus on exposures of aquatic organisms to persistent toxic chemical substances. Contaminants are transferred from the aquatic system to terrestrial animals by fish consumption (Ellis, 1989). Species that eat high on the food chain are more likely to experience adverse effects if biomagnification of persistent toxics is involved. Transfer of such contaminants via the food chain is of greatest concern for what are described as chlorine-containing bioaccumulative chemical substances, such as dioxins, PCBs, DDT and mirex.

There may be a delay between the time of discharge and the time at which the biological effect occurs. The chemical substances in an effluent may be in solution or associated with particulates. Dissolved chemical substances may be taken up by the organism directly and rapidly through respiratory surfaces or by surface sorption. The particulates (and adsorbed chemical) may degrade in the water column (releasing adsorbed chemicals), be ingested by organisms or settle to the bottom and become incorporated in the sediment.

If the chemical substance is not rapidly degraded and it becomes associated with sediments, the release may be slow or episodic. Chemical compounds present in the sediment may be slowly degraded there, be released to the water column through re-suspension or taken up by benthic organisms. The chemical substances may then be transferred from organisms to organisms via the food chain or may be metabolized and metabolites released to the water or sediment.

Community Effects. Studies on river systems exposed to industrial effluents containing persistent toxics show that benthic flora and fauna communities are adversely affected in relation to the distance from the discharge (Owens, 1991; Landner, Nillson and Rosenberg, 1977). Species diversity and population density of algae, plants, fish and micro- and macro-invertebrates increased with distance from discharge. However, it is difficult to separate whether the observed effects are from the presence of persistent toxic substances or are caused by physical, organic and nutrient components of the discharge (such as increased nutrient loading, increased release of colored substances, or suspended solid release). The isolation of specific chlorine process-related ecosystem effects have not been carried out in the field studies to date (Solomon *et al*., 1993).

Population and Organismal Effects. Numerous studies have implicated population and species effects of *specific persistent* toxic chlorinated compounds. DDT, methoxychlor, mirex are known to be estrogenic in birds (Fry and Toone, 1981; Eroschenko and Palmiter, 1980). TCDD results in marked feminization at the anatomical, physiological and behavioral levels in male rats (Colborn and Clement, 1992). DDT and DDE induce feminization in male gull embryos (Fry *et al*., 1987; Fry and Toone, 1981). Some hormonal effects in herring gulls have been correlated with TCDD levels, however, some may result from chronic exposure to steroids derived from plant sterols. The hormone synthesizing ability of testes of Atlantic cod was impaired by PCBs (Freeman, Sangalang and Uthe, 1984; Freeman, Sangalang and Flemming, 1982). Other organisms affected include: reduced egg production in zooplankton with PCBs (Aroclor 1221 and Aroclor 1254), reproductive failure in common seals attributed to PCBs and/or PCB-metabolites,

endocrine system interference from PCBs in female Baltic ringed seals, poor breeding success of Western gulls attributed to DDT and feminization of gull embryos (Reijnders and Brasseur, 1992; Reijnders, 1986).

Mounting evidence continues to suggest that the reduction of persistent toxic substances into the Great Lakes ecosystem has had an influence on reducing many of the more overt impacts previously observed in resident biological organisms (Willes *et al*., 1993; Solomon *et al*., 1993; Limno-Tech, Inc., 1993). PCB and DDT levels in water have decreased in many areas. Levels of these chemical substances in fish, wildlife and sediment have decreased in the last 20 years. Populations of certain avian species have shown significant recovery (Giesy, Ludwig and Tillitt, 1994; IJC, 1993; Brewer, McPeek and Adams, 1991).

Substitutes. Few studies have addressed changes in ecosystems after introduction of substitutes. The use of chlorine dioxide as a substitute for chloride in the bleaching process of pulp mills shows an approximate five- to ten-fold reduction in chlorinated compound discharge and a decrease in production of polychlorinated substances. These changes reduce persistence and toxicity and the potential for bioaccumulation. The formation of highly hydrophobic chemical compounds such as dioxins is substantially reduced to levels below detection. Improved effluent secondary wastewater treatment also has significantly decreased discharge of chlorinated compounds. Studies on the substitution of chlorine dioxide in the Grande Prairie mill on the Wapiti river in Western Canada did show reduction in chlorinated compounds in fish tissues (Swanson *et al*., 1993; 1992). Microcosm studies in experimentally manipulated systems indicate reduced fish mortality and decreased direct effects on macro-invertebrates (Rosemarin, Lehtinen and Notini, 1990).

Animal Toxicological Studies

The evaluation of the toxicity of chemical substances is usually accomplished using laboratory animals given high doses of the compounds to be tested. The chemical compounds may be given as a single dose or administered repeatedly over a period of time up to and including the lifetime of an animal. Isolated tissues and cells from laboratory animals are often exposed to chemical substances for short periods of time in an attempt to establish the molecular mechanisms by which damage can occur. Consideration of the published scientific literature pertaining to laboratory animal experiments on the toxicity of chlorinated compounds and other types of chemical compounds can provide insight into the premise that chlorinated compounds as a class exhibit a particularly high potential for toxicity.

Prevalence of Toxic Chlorinated Compounds. Lists of toxic chemical substances have been constructed by a variety of governmental agencies and public interest groups. The purpose of these lists is to concentrate regulatory attention on particular chemical substances thereby increasing efficiency in dealing with the problems of environmental pollution. One such list developed by the Great Lakes Water Quality Board in 1985 indicated 11 chemical substances as critical pollutants in the Great Lakes basin (IJC,

1987). Eight of the listed chemical substances contained chlorine and prompted the IJC Virtual Elimination Task Force to conclude that chlorinated compounds were a dominant threat (IJC, 1993). Although many different lists of suspected or proven chemical compounds can be consulted, the percentage of chlorinated compounds contained on Michigan Chemical Hazard Assessment List, 1986-1990, was calculated by MESB. Of the 750 chemical substances on that list, 38% contained one or more chlorine atoms. This degree of prevalence for chlorinated compounds is similar in most large lists of toxic chemical substances (e.g., see Appendix II) and possibly reflects the high frequency with which chlorine is used in synthetic organic chemistry and in chemical processes.

Persistent Toxic Chlorinated Compounds. Included on the IJC list of critical pollutants in the Great Lakes basin were PCBs, dioxins (TCDDs), furans (TCDFs), and the chlorinated hydrocarbon insecticides: DDT, mirex, toxaphene, dieldrin and hexachlorobenzene. All of these chemical substances exhibit toxicity of various types when tested in laboratory animals. Because of their relatively high solubility in lipid and because of their very slow degradation in the environment, they accumulate in the food chain and in mammalian and avian species that reside at the top of that chain. The combination of persistence, bioaccumulation and inherent toxicity makes them critical pollutants and evidence has accumulated that sensitive species of wildlife have exhibited effects when levels of exposure have been sufficiently high (Colborn, vom Saal and Soto, 1993).

Considering the toxicity of PCBs and TCDDs in laboratory animals, there is little doubt of the *potential* for human and environmental harm provided by the critical pollutant chlorinated compounds mentioned above. Clearly, when exposure to these environmental pollutants is high enough, toxicity will be observed. Current evidence indicates that previous levels of these contaminants in the environment have declined but the rate of decline has slowed as point sources have been eliminated and loading to environmental media becomes diffuse and relatively more atmospheric. The elimination of the use and/or release of these persistent chlorinated chemical compounds is underway and must be completed to maximally reduce their environmental and public health liabilities.

Common Solvents. Chlorinated volatile hydrocarbons are a subgroup of chlorinated compounds possessing properties that permit them to be used as solvents in industry. Solvents such as methylene chloride, carbon tetrachloride, trichloroethylene and perchloroethylene possess the ability to cause central nervous depression (e.g., sedation) and liver damage when given in high doses to laboratory animals. These effects have been observed in humans after accidental or occupational exposures (Ellenhorn and Barceloux, 1988). While liver tumors can be produced by many of these chlorinated solvents after long term exposures to rodents, there is no evidence that tumors are produced in humans. It is currently believed that the strain of mice used in the rodent bioassay for cancer possess a unique susceptibility to liver cancer. This makes the use of these mice as a model for predicting human liver cancer suspect (Goodman, 1994).

Volatile organic solvents, including those containing chlorine, are degraded in the

environment but can reach groundwater due to their adequate solubility in water. The presence of small concentrations of these substances in drinking water is common (Calabrese and Canada, 1986). They may appear in drinking water because of their mobility in soils and/or because they are created by the chlorination of drinking water supplies. In general, the presence of low concentrations of chlorinated volatile organic compounds in drinking water is not thought to produce a threat of human toxicity similar in magnitude to that attributable to the environmentally persistent, lipid soluble chlorinated compounds.

Vinyl chloride, a feedstock for the manufacture of polyvinyl chloride (PVC) plastic is a volatile chlorinated compound that is known to produce human liver cancer (angiosarcoma). Similar tumors are produced by this chemical substance when it is given to rats and mice (Maltoni *et al*., 1983). This type of cancer is very rare in the absence of exposure to vinyl chloride and therefore this chemical substance was easily identified as a known human carcinogen because of the high incidence of angiosarcoma in exposed workers (Manson, Peters and Johnson, 1975). No other chlorinated solvent produces this unusual tumor which supports the concept that the potential for harm resides in specific chlorinated chemical structures and not in all chlorinated compounds.

Biological Activity and the Chlorine Atom. Studies of the relationship between chemical structure and biological activity of drugs and known toxic chemical compounds have indicated that the presence of a chlorine atom or other halogen atoms (e.g., fluorine, bromine, iodine) can modify but does not dictate the type of biological activity that may reside in an organic molecule (Fischer, 1994). Whether or not an organic molecule will exhibit a particular toxic activity (or beneficial activity in the case of drugs) depends in part on the carbon-containing backbone of the molecule. Addition of chlorine at a specific position in the carbon-containing backbone may increase activity but further additions of chlorine atoms to other positions in the molecule will usually decrease activity. This concept is demonstrated by examining the binding affinity of PCB congeners to the receptor that initiates their biological activity (Kafafi *et al*., 1993). Receptor binding affinity, and presumably resulting activity, is highest when chlorine atoms are located in critical positions on the molecule and congeners containing eight chlorine atoms do not bind more strongly than congeners containing four chlorine atoms. Thus, the presence of chlorine atoms in an organic chemical substance may or may not increase its intrinsic toxicity.

The addition of multiple chlorine atoms on an organic molecule usually increases the resistance of the molecule for degradation in the environment. Thus, persistence is generally but not necessarily increased with increased numbers of chlorine (or bromine) atoms (Willes *et al*., 1993). If a molecule with multiple halogens exhibits biological activity, the greater will be the likelihood of a hazardous combination of persistence and toxicity. Persistence may lead to bioaccumulation which results in high concentrations of the chemical substance in the susceptible organism sufficient to observe its intrinsic toxic effects. Such is the case with DDT, and some isomers of the subclasses of chlorinated compounds (TCDDs and PCBs). It is necessary to point out that other isomers of these potentially troublesome subclasses of chlorinated compounds do not exhibit potent

toxicity (Safe, 1990). The presence of relatively non-toxic chlorine-containing isomers (congeners) within a commercial mixture of PCBs known to be toxic to laboratory animals underlines the important fact that the presence of chlorine atoms is not a requirement for an increase in toxicity.

Mixtures of Chlorinated Compounds. Environmental exposures to chemical compounds almost always involves a complex mixture. It is possible that the presence of other chemical compounds can increase, decrease or not change the toxic effects of a particular chemical substance present in a mixture. Because of the complex nature of environmental exposures, particularly the large number of known and unknown chemical compounds present, it is virtually impossible to adequately assess the toxicity of chemical mixtures. The number of qualitatively and quantitatively different mixtures that would require toxicity assessment would drain all imaginable resources. While research efforts to better understand the mechanistic basis for chemical interactions are valuable and continuing, it would be impracticable to systematically evaluate environmental chemical mixtures.

Certain subclasses of chlorinated compounds (e.g., PCBs and TCDDs) are often tested as mixtures and the toxicity from particular mixtures of these compounds can be predicted from knowledge of the toxic potential in each component of the mixture (Safe, 1990). These predictions of total toxic potential from known mixtures are possible because each component of the mixture acts in an identical manner (i.e., has the same mechanism of action) in the body. In the recent past, the total toxicity from environmental mixtures of PCBs and TCDDs have been calculated and used for regulatory purposes. It is now apparent that members of these subclasses of chlorinated compounds do not cause toxicity in animals by a single mechanism and that several different mechanisms may be involved. These recent findings call into question the accuracy of previous predictions of total toxicity from mixtures of PCBs and TCDDs and underscore the complexity of the interaction of chemical compounds. It should be appreciated that certain mixtures of PCBs and TCDDs are *less* toxic than can be predicted with known information (Safe, 1990). This potentially protective action within a mixture while rarely reported is scientifically plausible using known concepts of antagonism between chemical compounds which is often utilized in the development of drugs and antidotes.

Estrogenicity and Toxicity

The ability of a diverse group of natural and synthetic chemical substances to produce biological responses characteristic of natural estrogens is receiving much current attention in the scientific literature and in the press reporting science news. Many of these chemical substances have not previously been known to possess estrogenic activity (e.g., PCBs) while for many years others have been known to have estrogen-like properties (e.g., DDT). Whereas some of the estrogenic compounds contain chlorine, others, such as the mycotoxin zearalenone, do not contain chlorine. Potent, natural estrogens (e.g., estradiol) and many synthetic estrogens (e.g., diethylstilbestrol) do not contain chlorine. It is clear that to exhibit potent estrogenic activity a molecule does *not* require the presence of chlorine. The estrogenic activity found to be present in

environmental pollutants is weak, (e.g., 1/1000), when compared to the activity found in natural estrogens (Soto *et al*., 1992). This usually can be explained by the fact that the binding of environmental estrogenic material to the estrogen receptor in hormone sensitive tissues of the body (e.g., uterus, breast) is weak compared to the binding affinity of estradiol for the receptor. Compounds that weakly bind to the estrogen receptor can disrupt the binding and action of potent natural estrogens and in that manner act as antiestrogens.

Many current research projects are investigating the hypothesis that the presence of estrogenic chemical contaminants in the body contribute to the cause of reproductive dysfunction and chronic disease states known to involve estrogens (e.g., sexual development, breast cancer). Recently published information has indicated that wildlife in areas known to be more heavily contaminated are not reproducing normally. For example, eagle populations near heavily contaminated sites on the shore of the Great Lakes have declined and are not recovering, whereas, total populations are recovering (Bowerman, 1993). Eagles and other species depending on fish consumption may contain relatively higher levels of PCBs and other common contaminants normally found in fish (Gilbertson *et al*., 1991). Controlled feeding studies in mink have indicated that Great Lakes fish can produce reproduction deficits in that species (Hornshaw, Aulerich and Johnson, 1983). Recent studies employing single, low doses of 2,3,7,8-TCDD have indicated that the male offspring of exposed pregnant animals have reproductive abnormalities and exhibit signs of feminization (Peterson, Theobald and Kimmel, 1993; Mably *et al*., 1992).

It remains hypothetical whether changes in the reproductive system in humans, including decreased sperm counts, masculinization of females and feminization of males, can be attributed to exposure to environmental estrogens or antiestrogens. A similar statement can be made for environmental estrogens (e.g., DDT and PCBs) as a contributing cause to human breast cancer (Davis *et al*, 1993). Much additional basic research is needed to understand the action of these agents and to determine whether environmental exposures engender a reproductive or cancer risk.

Human Epidemiologic Studies

This discussion presents an overview of selected epidemiologic findings pertaining to exposure of human populations to certain chlorinated compounds. Particular attention has been paid to environmentally persistent and toxic chlorinated compounds and the potential human health outcomes of cancer and adverse reproductive effects. A comprehensive, in depth discussion of the health effects of the approximately 15,000 synthetically-produced chlorinated compounds presently in use is beyond the scope of this review.

Human epidemiologic studies are generally classified either as descriptive or analytical. Descriptive studies are those exploring disease cross-sectional patterns and trends over time. Often included in descriptive epidemiologic studies are those described as "*ecological*." Ecological studies often correlate economic, social or environmental

occurrences with patterns of human disease. Analytical studies are usually of the case-control or cohort designs. Case-control studies identify cases affected by a particular disease outcome and a control group, comparing targeted exposure proportions in each group. Cohort studies, typically more expensive and involving more study subjects, begin by classifying populations as either exposed or unexposed to an agent of concern, and prospectively identify numbers and percentages in each group who subsequently develop selected diseases. For the purposes of this review, it is important to realize that epidemiological studies do not, in and of themselves, provide absolute proof of causality; neither do they disprove it. They do provide one component of proof, a measure of association. Since prospective, randomized studies, exposing human populations to known toxins are unethical, epidemiologic studies often provide the best available assessment for toxicity among human populations. For example, the current knowledge that cigarettes cause lung cancer was arrived at in large part through a series of epidemiologic case-control and cohort studies.

Epidemiologic studies have strengths and limitations. They often help to validate hypotheses generated from animal, cellular and molecular based studies. They provide a window of true impact of toxic exposures on human populations. They provide important trend data, such as rising or lowering trends of cancer, which help form public policy. Human epidemiologic studies are limited by their need to include large numbers of subjects. Associated with these large numbers is high cost. For example, a typical epidemiologic study assessing several hundred cases of cancer and controls, and exploring possible environmental etiologies, will be of a probable duration of three to five years, at a cost of several hundred thousand dollars annually. Epidemiologic studies are often challenged by numerous confounding etiologies. Although these potential confounding factors can often be controlled statistically, the almost unlimited number of *unknown* confounding factors presents a continuing challenge. This is particularly important in the current endeavors of the Panel because toxic effects of chlorinated compounds in humans may be confounded by affects of non-chlorinated chemical compounds, diet, genetics, etc. Finally, epidemiologic studies rarely benefit from sufficient detail to accurately quantify dose of exposure. Similarly, routes of exposure (e.g., inhalation, ingestion) are often missing. Even with these limitations in mind, epidemiologic studies often provide the best available evidence for toxic environmental hazards as they might affect human populations.

Environmental Trends. Time trends, both of suspected exposure to certain chlorinated chemical substances, and of disease outcomes which are considered etiologically linked to these exposures, provide much of the background for public concern. As the Panel is being asked to provide opinions on conclusions reached by the IJC, exposures of concern are focused on water-borne sources of chlorinated chemical substances. Levels of persistent chlorinated substances, including PCBs and DDT, in fish from Michigan waters are often cited. For example, levels of PCB concentrations in the Great Lakes, measured by levels in whole Lake trout from 1972-1990, show a decline from the peak years of 1974 and 1975. Yet levels of PCBs and DDT in Coho salmon of the Grand, Platte, and St. Joseph Rivers of Michigan remain at measurable levels between 1983 and 1992 (MDNR, 1993). Even with trends to lower water levels of toxins, some sites still

show the presence of bioaccumulated levels in edible fish. This may be due to flow release of these toxins from previously contaminated sites.

Human disease trends may also be noteworthy. For example, several investigators have identified a secular trend of decreasing sperm counts in human populations (Sharpe, 1993; Carlsen *et al*., 1992). Increasing rates of cancer are also being noted in the U.S. and Michigan, even after controlling for potential confounders of cigarette smoking and age (Davis, Dinse and Hoel, 1994; Miller, 1994; Miller *et al*., 1993). Trends are being noted also in the southeast Michigan area for dramatic rises in prostate cancer, adenocarcinoma of the esophagus, carcinoma *in situ* of the uterine cervix, and a consistent rise in breast cancer (Demers, 1994).

Health Concerns With Exposure to Dioxins. Dioxins are a widespread group of chemical compounds which originate as undesirable by-products from numerous sources. The USEPA and the National Institute of Occupational Safety and Health consider one of the dioxins, 2,3,7,8-TCDD, to be a probable human carcinogen and a cancer promoter. TCDD carcinogenicity in animals is well known. Human epidemiologic studies have linked soft tissue sarcoma and non-Hodgkin's lymphoma with exposure to dioxins (Woods *et al*., 1987; Fingerhut *et al*., 1984). Considerable data on dioxin exposure among community populations and occupational groups are available through accidental exposures. Noteworthy were the accidental exposures of people living near an industrial plant in Seveso, Italy, and to workers in a chemical plant contaminated with dioxin in Germany (Axelson, 1993; Bertazzi *et al*., 1993; Manz *et al*., 1991). These studies showed an association between dioxin exposure and sarcomas and hematogenous malignancies. These and other epidemiological studies reviewing dioxin exposure have led the International Agency for Research on Cancer (IARC) to conclude that exposure to polychlorinated dioxins "*has been shown in some studies to be associated with soft tissue sarcoma, lymphoma, stomach cancer, and nasal cancer, but no outcome has been conclusively established or rejected* " (Fingerhut *et al*., 1991).

Refinements in the ability to measure dioxin levels in human serum have facilitated exploration into possible mechanisms of toxicity of dioxin. Epidemiologic studies which quantify exposures by measuring human tissue levels of toxins provide investigators with an opportunity to associate exposure with outcomes of either disease, or intermediates of disease. For example, Egeland *et al*. (1994) recently showed an alteration in sex hormone levels in workers exposed to dioxins. This study may contribute needed information pertaining to evidence of an intermediate step between dioxin exposure and the development of cancers that may be hormone dependent.

Polychlorinated Biphenyls. The PCBs have long been suspected to cause adverse health effects in humans, including skin rash and elevation of liver enzymes (Kimbrough, 1987). Their association with long-term exposure effects are more difficult to study and, therefore, more controversial. PCBs are considered a cause of cancer in animals and possibly in humans (ATSDR, 1989). A recent study has implicated PCB residue in human breast lipids as associated with breast cancer (Falck *et al*., 1992). Other authors have identified associations of PCB ingestion in children with altered childhood growth

and physical activity levels (Jacobson, Jacobson and Humphrey, 1990; 1989). Yet other authors following cohorts of industrial workers highly exposed to PCBs have found no statistically significant health effects (James *et al*., 1993). Long-term human health effects of PCB exposure remain to be proven.

Endocrine Sensitive Malignancies. Breast cancer, prostate cancer and testicular cancer are each showing epidemiologic trends of increase. Since each of these cancers is known to be hormone sensitive, investigators are beginning to explore possible associations between endogenous and exogenous hormone levels. Since hormone disrupters are known to include chlorinated hydrocarbons, (e.g., DDT, PCB and dioxins) consideration is given to the possibility that substances which mimic estrogen in the human body could serve as promoters of hormone-sensitive cancers. Recent associations between farming occupations and prostate cancer, with the suspicion of an herbicide link, provide hypothetical evidence for the role of herbicides (which include some chlorinated compounds) as prostate cancer promoters (Morrison *et al*., 1993). *In utero* exposures to exogenous hormones taken by mothers led other authors to suspect an estrogen influence on the development of testicular cancer in male offspring (Henderson *et al*., 1979). Other studies have attempted to implicate exposure to DDT and its metabolites, and PCBs in the development of female breast cancer (Wolf *et al*., 1993; Falck *et al*., 1992). A more recent study by Krieger *et al*. (1994) showed no association between serum PCB or DDE and breast cancer in women. Increasing consideration is being given to possible etiological links between estrogen-simulating chemical substances of environmental origin (often chlorinated compounds) and the development of hormone-sensitive malignancy.

Diversity of Human Exposures to Chlorinated Compounds. The focus thus far has been mainly on epidemiological studies involving two large classes of persistent chlorinated compounds; the dioxins and PCBs. To a lesser extent, mention has been made of DDT, a persistent pesticide whose use has been restricted in the U.S. in recent years. Chlorinated compounds, however, constitute a large and diverse grouping of chemical substances. Certain non-persistent chlorinated compounds which are widely used in the workplace are known to cause adverse health effects. The epidemiologic literature involving occupational exposures is replete with reference to studies of these various chlorinated compounds. Selected examples are presented below.

Methylene chloride is commonly used in both industrial and home environments as a solvent and degreaser. Epidemiologic studies have shown methylene chloride to have acute central nervous system depressant properties. Methylene chloride is also known to be a cardiac toxin, secondary to its metabolism to carbon monoxide after human exposure. The USEPA also considers methylene chloride to be a probable human carcinogen (USEPA, 1985; Ott *et al*., 1983; Ratney, Wegman and Elkins, 1974). Chronic health effects from exposure to methylene chloride are more difficult to substantiate (Soden, 1993).

Reproductive effects, particularly of sperm count depression, have been documented for dibromochloropropane (DBCP) over the past decade. These findings have also been

shown to be persistent among workers manufacturing this compound. Similar effects on the sperm count have been revealed more recently in pesticide applicators exposed to DBCP (Levine *et al*., 1983; 1981; Glass, 1980; Glass *et al*., 1979).

Trichloroethylene (TCE) is a commonly used industrial solvent which is a frequent contaminant of drinking water in the state of Michigan. Epidemiologic studies have shown TCE to be a central nervous system depressant and a suspected hepatic, renal and pulmonary toxin in humans (ATSDR, 1989b; Forkert, Syulvestre and Poland, 1985; Smith, 1966).

Perchloroethylene (PERC), also known as tetrachloroethylene, is commonly used in the processes of dry cleaning and metal degreasing. As with many other chlorinated organic solvents, PERC is known to cause central nervous system depression, peripheral neuropathy and liver toxicity (CDC, 1983).

Pentachlorophenol (PCP) has been used as a preservative in the manufacture and treatment of a variety of commercial products. PCP prevents decay from micro-organisms such as molds and fungus. PCP has been associated in various epidemiological studies with neurologic effects (especially hyperthermia), hepatotoxicity and transient renal toxicity. Hodgkin's Disease and soft tissue sarcoma have also been linked to PCP exposure (Thind, Karmali and House, 1991; Gilbert *et al*., 1990).

A review of 23 studies published in 1993 concluded that chlorinated hydrocarbon solvents as a general class are associated with elevated risks of leukemia, lymphoma and urinary bladder cancer (Frangos and Peters, 1993).

Chlorinated Drinking Water. Epidemiologic studies pertaining to possible adverse health human health effects related to chlorinated drinking water have been summarized in a recent monograph published by IARC (1991). In addition, Zeighami, Watson and Craun (1990), in a cross-sectional study of 1,500 healthy individuals, noted a statistically significant higher blood cholesterol in female participants who consumed chlorinated versus non-chlorinated drinking water. Adverse reproductive effects were studied by Rausch (1977) in New York and Hertz-Picciotto *et al*. (1989) in California with conflicting results, the former showing a protective effect on fetal outcomes, and the latter a positive association.

Human epidemiologic studies of the impact of chlorinated drinking water on cancer have been, for the most part, negative. However, possible associations have been identified for lower intestinal cancer and urinary bladder malignancy (Zierler *et al*., 1988; Cantor *et al*., 1987; Gottlieb and Carr, 1982; Wilkins and Comstock, 1981; DeRouen and Diem, 1977). A meta-analyses of 12 U.S. studies conducted by Morris in 1992, concluded that a moderate (1.15) statistically significant elevation of relative risk for all cancers existed in association with consumption of chlorination by-products in drinking water. Shortcomings of these epidemiologic studies are pointed out in the IARC monograph (IARC, 1991). One major shortcoming is the fact that most studies do not adequately quantify lifetime intake of chlorinated water. Also, urban status and other potential confounders often

influence study outcomes. For example, use of chlorinated water is often associated with urban residence, which in turn may be highly associated with elevated cancer rates. Overall, the conclusion in the IARC monograph was "*there is inadequate evidence for the carcinogenicity of chlorinated drinking water in humans*" (IARC, 1991).

An exhaustive human epidemiology review of the health effects of chlorinated compounds was not the purpose of this section. Such an attempt would be futile because of the sheer numbers of these compounds and related studies, and the fact that a majority of chlorinated compounds will not have been studied epidemiologically. Rather, the attempt here was to provide a brief survey of selected studies of chlorinated compounds as are found in the Michigan environment. Studies of each of these compounds include those of positive and negative results. Applying a summary statement to the overall toxicity of chlorinated compounds as a group is difficult, if possible at all. However, toxicity of selected members of this group is evident, as identified with several examples above, and the prevalence of chlorinated compounds in Michigan waters warrants continued diligence in studying their health effects.

Chlorine Substitutes

It is estimated that 15,000 of the 70,000 chemical compounds in commerce today are chlorinated (Ehrenfeld *et al*., 1993). If the use of chlorine and chlorinated compounds is sunset, some form of non-chlorine based substitute would take their place. A critical question is whether these non-chlorine substitutes would be safer and what economic and social sacrifices would be required to make the switch. A simple answer to these questions is not possible due to the numerous uses of chlorine-based products. As a consequence, it is not the intent of this discussion to provide an exhaustive compilation of what the potential non-chlorinated substitutes would or could be, as well as their comparative quality, cost and safety to the target chlorine-based product. A brief discussion of some of the largest and more well-known uses of chlorine based products and their substitutes is presented below.

Polyvinyl Chloride (PVC). The largest use of chlorine (about 26%) is in the production of vinyl chloride monomer which is a precursor of PVC (Ehrenfeld *et al*., 1993; Charles River Associates, 1993; Kirschner, 1993). PVC accounts for about 15% of all plastic sales in the U.S. (Ehrenfeld *et al*., 1993). There are literally thousands of uses of PVC, including food packaging, flooring, siding, bottles and pipes. PVC is incorporated into automobiles, furniture, buildings, sports equipment, medical supplies, footwear and many other products.

PVC has replaced metals, glass, rubber, wood, paper, cement, ceramics and other plastics either because it was less expensive or it offered better performance characteristics. Thus, loss of PVC would mean higher product costs and/or some sacrifice in performance, as well as a different set of potential environmental hazards. The extent of the added costs, performance loss, or environmental problems depends on the substitutes available, and these substitutes vary widely across the different uses of PVC.

To illustrate, building and construction accounts for about 60% of all PVC use (Ehrenfeld *et al*., 1993; Johnson, 1991). Pipes, fittings, and conduits account for one third of all building and construction uses of PVC (the second largest construction use, 24% is resin-bonded woods). PVC is used in pipes, fittings and conduits because it does not corrode or conduct electricity as metals do, and it is more durable and energy efficient. The likely non-chlorine substitute for PVC pipe would depend on the use. For example, the most likely substitute for PVC in small diameter pipes is polyethylene (Ehrenfeld *et al*., 1993; Charles River Associates, 1993). However, ductile iron may be the most likely substitute in sewer and drain pipes (Charles River Associates, 1993).

A similar extrusion technology is used to produce pipes from polyethylene compared to PVC. However, polyethylene is more costly to use and has some limitations in comparability of performance. There may also be environmental problems associated with polyethylene, but their extent is unknown (Ehrenfeld *et al*., 1993). In contrast, increased ductile iron use will require substantial capital investment as well as increased costs per foot installed. Producing ductile iron also results in adverse environmental impacts (Charles River Associates, 1993).

The second largest use of PVC is in packaging (about 8%), particularly bottles (Ehrenfeld *et al*., 1993). PVC use in packaging is being phased out in some European countries (Johnson, 1991). The primary substitute being used in bottles is polyethylene terephthalate (PET). Coca-Cola and Pepsi-Cola Companies have announced that they plan to use PET bottles, and that PET is more easily and fully recyclable than PVC. PET is more costly to use in making bottles than PVC. However, PET has some performance advantages over PVC, particularly in bottling of carbonated beverages (Ehrenfeld *et al*., 1993).

Pulp and Paper. The second largest use of chlorine (about 14%) is pulp and paper production (Charles River Associates, 1993). Chlorine bleaching is the primary means of removing residual lignin in wood pulp. In 1992, there were approximately 600 paper mills in the U.S., 104 of which produced bleached kraft pulp. Twelve bleached kraft pulp mills are located within the Great Lakes basin, three of which are in Michigan (Lockwood-Post Directory, 1992). All of the mills use chlorine. Michigan also has approximately 242 pulp and paper and allied manufacturing facilities (USDC, 1993).

It is possible to produce high quality paper from virgin pulp and recycled fibers without using chlorine. The primary non-chlorine substitutes for bleaching pulp are oxygen delignification, ozone bleaching and peroxide bleaching (Ehrenfeld *et al*., 1993; Patrick, 1993; Colodette *et al*., 1993). Because of the increased demand for chlorine-free paper in Europe, some pulp mills serving those markets have begun to use chlorine-free processes. There is one chlorine-free paper mill located in the U.S. (in Samoa, California) (Kriz, 1994). Although it is technically feasible to eliminate chlorine from paper production while maintaining adequate product quality, the relative safety of chlorine-free processes remains to be documented.

A ban on chlorine would also affect the use of caustic soda, a co-product of chlorine production in paper mills. As production of caustic soda from alternative methods is undertaken (i.e., using soda ash), increased caustic soda costs will encourage the use of alternative alkali sources in pulp bleaching (Naddeo *et al*., 1992).

The primary argument against requiring totally chlorine-free processes is that recent environmental improvement investments by the paper industry have significantly reduced dioxins and other persistent chlorinated compounds. Many U.S. mills producing bleached pulp have recently retooled their operations in order to take advantage of a chlorine dioxide technology that significantly reduces (e.g., 90%) dioxin levels in pulp wastewater (Ehrenfeld *et al*., 1993). The sunsetting of chlorine as an industrial feedstock would presumably eliminate this technology. Since there is only one U.S. plant that uses totally chlorine-free technology, nearly all U.S. plants would have to be retooled if the use of chlorine and chlorine compounds was banned.

Solvents. The third largest use of chlorine is solvents (9%) such as carbon tetrachloride, methylene chloride, chloroform, TCE, PERC and 1,1,1-trichloroethane (Charles River Associates, 1993; Ehrenfeld *et al*., 1993). These solvents have been used for cleaning and extraction in a wide variety of industrial processes as well as in commercial dry cleaning. Nearly 800,000 tons of these solvents were consumed in 1990 in the U.S. and Canada (Charles River Associates, 1993).

Over the past several decades, there have been a large number of substitutions in the types of solvents used in industry for safety and environmental reasons. For example, carbon tetrachloride was substituted for aliphatic and aromatic hydrocarbon solvents in order to prevent fire and explosion hazards. TCE was substituted for carbon tetrachloride to prevent acute toxicity to humans. PERC and methylene chloride were substituted for TCE in order to prevent carcinogenicity hazards (Frangos and Peters, 1993). Until the early 1990s, CFC-113 (chlorofluorocarbon) was a major chlorinated solvent, but its use is being phased out under the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer (Macauley, Bowes and Palmer, 1992). Regulations on TCE emissions from metal cleaning operations have led to increased substitution of 1,1,1-trichloroethane for TCE in metal cleaning (Macauley, Bowes and Palmer, 1992).

PERC is the primary solvent used in dry cleaning and its use is increasing as production of CFC-113 is being phased out. Nearly 90% of TCE is used in vapor degreasing and metal cleaning. Trichloroethane is used in metal cleaning, aerosols, adhesives, coatings and inks, and electronics. Methylene chloride is used in aerosols, paint removers, foam blowing, metal cleaning and electronics, and in chemical processing such as the manufacture of pharmaceuticals and photographic film (Frangos and Peters, 1993; Charles River Associates, 1993; Macauley, Bowes, and Palmer, 1992).

Non-chlorine substitutes for solvents vary by type of use. Since there are many different uses, it is difficult to determine what number of the potential substitutes might be used, as well as their safety and efficacy. The following two paragraphs describe substitution possibilities for dry cleaning and industrial cleaning.

The existing technical substitutes for PERC in dry cleaning are CFC-113 and various flammable hydrocarbon solvents. However, none of these substitutes can be used legally. CFC-113 is being phased out under the 1987 Montreal Protocol. Flammable hydrocarbon solvents are banned under the National Fire Protection Codes (Macauley, Bowes, and Palmer, 1992). The USEPA recently announced that a joint USEPA/industry effort has demonstrated the technical viability of a wet cleaning process for garments. This new process drastically reduces the use of PERC, but does not eliminate it. The USEPA has yet to examine the health and ecological effects of the wet cleaning process, so it has not determined whether it is a viable pollution prevention option for the dry cleaning industry (USEPA, 1993a).

TCE is used by machinists, auto repair shops, metal furniture manufacturers and metal parts fabricators to remove dirt and grease from metal parts. TCE and PERC are used for vapor degreasing in manufacturing processes using glass, metal and other nonporous materials. The substitutes for cold metal cleaning and vapor degreasing are aqueous and semi-aqueous processes. These water-based processes have adverse impacts including potential rusting, creation of residual films, creation of water pollution and longer drying times. Hydrocarbon solvents are also possible substitutes, but their use is limited by local fire codes (Macauley, Bowes, and Palmer, 1992). However, electrical equipment manufacturers using vapor degreasing are in the process of switching to aqueous and semi-aqueous cleaning methods as well as using no-clean techniques (Ehrenfeld *et al*., 1993; Macauley, Bowes, and Palmer, 1992). These methods are not suitable for all electronic production processes and may have some adverse environmental impacts.

Water Treatment. Perhaps the most well-known use of chlorine, water disinfection, is one of the smallest use categories (5%). Chlorine is used to remove pathogens from drinking water and to treat sewage effluents. Virtually all U.S. water treatment facilities use chlorine for disinfection. According to the Michigan Department of Public Health (MDPH, 1994), there are 126 water treatment plants in Michigan.

Elemental chlorine levels in water treatment levels are highly regulated by government. In order to reduce chlorine levels, some plants have begun using sodium chlorite (Ainsworth, 1993). Sodium chlorite reduces chlorine levels and has been in use in water treatment for over 50 years.

There are non-chlorine substitutes for disinfecting water, but they have some limitations in terms of performance and cost. The most likely substitute is ozonation, a process that is widely used in Europe and about 40 U.S. water treatment facilities. Ozonation disinfects water at the treatment plant, but does not prevent recontamination once the water leaves the plant. It is also extremely costly for small scale water treatment facilities, though it is economically viable for larger facilities (Cleland, 1994).

Other Important Chlorine Uses. While other uses of chlorine do not require large volumes, they include some highly valued uses. For example, many pharmaceuticals contain chlorine, including: antibiotics, cardiovascular drugs, and several of the most

widely used antianxiety and antidepressant medications (e.g., valium). Chlorine is also widely used as a reagent in making drugs that do not contain chlorine. Similarly, it is estimated that between 30% to 40% of all pesticides contain chlorine, including six of the ten most widely used pesticides in the U.S. (Ehrenfeld *et al*., 1993). The availability of substitutes for these pesticides will vary by type of pest and crop.

Conclusions

1. The known toxicity of certain chlorinated compounds, particularly those exhibiting persistence, and the possibility that *unknown* products of similar toxic potential are now reaching the environment, or may do so in the future, makes it necessary to evaluate current and future uses of chlorine and chlorinated compounds. Discussions, similar to those called for by the IJC, should take place among industry, government and public interest groups to examine the risks and benefits of the chlorinated products in use. Included in these discussions should be the consideration of safety and effectiveness of possible alternatives to chlorine-containing compounds and processes. The timetable for these discussions and the actions resulting from them should be reflective of sound science, the current importance of chlorine to society and the lack of alternatives of known safety and effectiveness. It would seem reasonable that known and suspected harmful chlorinated compounds or processes would be eliminated over a period of 30 years or less using a priority system addressing health, economic and other societal factors.

2. The addition of chlorine atoms to an organic molecule usually increases its solubility in lipid and often increases the length of time it is present in the environment. The combination of lipid solubility and environmental persistence can result in accumulation of organic compounds in the food chain. In general, a toxic compound which is bioaccumulating in the environment, particularly in the food chain represents a greater threat to environmental and public health when compared to the threat from an equally toxic compound that does not bioaccumulate.

3. The grouping of chemical substances for regulatory purposes on the basis of physical, chemical and biological characteristics is scientifically defensible whereas consideration of a single property (e.g., contains chlorine) alone is likely to be inadequate for the intended purpose. Thus, persistent toxic chlorinated and non-chlorinated compounds released to the environment can be treated as a group for the purpose of regulatory control. Toxic compounds currently known to be persistent and bioaccumulative in the environment should be vigorously controlled. Procedures to adequately detect these and the many unknown compounds either individually or as mixtures should be implemented.

4. Scientific evidence indicates that all chlorine-containing organic compounds do not have similar potential to produce deleterious effects in humans and in the environment.

5. There is *insufficient* scientific evidence to indicate that the mere presence of non-persistent chlorinated compounds in the environment is producing an environmental or public health threat. Likewise, *insufficient* evidence does not prove lack of potential for

harm.

6. Some non-persistent chlorinated compounds including certain volatile organic solvents can produce toxic effects at high exposures that may occur with accidents or in occupational settings. The ability of these types of chemical substances to produce long lasting health effects such as cancer, neurological damage or reproductive deficits as a result of lower environmental exposures is generally not convincing at this time. Sunsetting of this group of chemical compounds should not occur precipitously.

7. New chlorinated and non-chlorinated products and by-products of industrial processes should be evaluated for their toxicity, persistence and bioconcentration potential prior to being released into commerce and the environment. The toxicity testing applied to products, emissions and effluents from new industrial processes should be sufficiently sensitive to detect adverse effects that might occur in wildlife, domestic animals and humans at concentrations known or reasonably estimated to occur in the environment. The testing paradigm applied should be capable of detecting several types of non-lethal toxic effects including those leading to neurotoxicity, hormone modulation resulting in reproductive and developmental toxicities and immunotoxicity. If the testing paradigm now being used cannot detect the toxic effects of chemical compounds currently considered to be particularly hazardous (e.g., 2,3,7,8-TCDD) when they are present in concentrations above scientifically sound regulatory standards, it should be considered inadequate for protection of public and environmental health and replaced with a more appropriate protocol.

8. Previously installed industrial processes for which there is inadequate information regarding the identity and/or toxicity of the by-products released to the environment should be subjected to an adequate toxicity testing paradigm. This should be done to provide data indicating the potential of released unknown by-products to produce harm to the environment and public health, and sufficient information to allow a risk/benefit evaluation to be made.

9. The replacement of chlorine and potentially toxic chlorinated compounds in industrial processes with equally beneficial alternative chemical compounds and processes will require toxicity testing for a new set of products and by-products. Studies involving the use of intact animals, cells and isolated tissues derived from animals will be required. The efficacy of the tests used to evaluate the safety of alternative products and the associated by-products should be equivalent to tests required for chlorine-containing products and by-products.

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DIRECTIVE 2. Evaluate whether Michigan's body of regulations affecting the use of chlorine and chlorinated compounds adequately protect Michigan's citizens' health, the environment and the Great Lakes.

Introduction

The purpose of this portion of the report is to evaluate the ability of Michigan's regulations to adequately protect public health and the environment from impacts associated with the use of chlorine and chlorinated compounds.

Description of Existing Regulations

Table 2 lists the various federal and Michigan laws which have either a direct or indirect impact on the use of chlorine and chlorinated compounds within Michigan. With the exceptions of the federal Toxic Substance Control Act of 1976; Food, Drug and Cosmetic Act of 1938; and Pollution Prevention Act of 1990, and portions of the federal Clean Air Act of 1963; Hazardous Materials Transportation Act of 1978; and Insecticide, Fungicide and Rodenticide Act of 1972, the federal regulations listed are either incorporated in part or entirely by reference into the state's regulatory counterpart. The 14 Michigan regulations and their respective administrative rules are administered by five different state departments: Departments of Agriculture, Labor, Natural Resources, Public Health and State Police. Several of the Michigan regulations are jointly administered. A brief summary of the pertinent sections of each of the identified federal and Michigan regulations is presented in Appendix II.

Discussion

Prior to and since the IJC issued its initial 1992 recommendation to sunset chlorine, there have been several federal regulatory framework reviews and evaluations conducted, both comprehensive and cursory (IJC, 1993; IJC, 1992a; Jarrell, 1992; Foran and Jarrell, 1991; USGAO, 1991; Henschler, 1990). The reviews conducted by the IJC Virtual Elimination Task Force (IJC, 1993), IJC Great Lakes Water Quality Board (IJC, 1992a) and the U. S. General Administration Office (USGAO, 1991) most closely parallel the second charge to the MESB Chlorine Panel.

Both the IJC Great Lakes Water Quality Board (IJC, 1992a) and the IJC Virtual Elimination Task Force (IJC, 1993) looked at the adequacy of current U.S. and Canadian federal regulations from the basis of their ability to achieve the virtual elimination of persistent toxic substances. In conducting its evaluations, the Great Lakes Water Quality Board (IJC, 1992a) differentiated between legal authority and effective authority. Both studies concluded that, while the current regulations did provide the necessary legal authority to achieve virtual elimination, neither country was implementing its laws to the fullest, due to both inadequate staff and resources. Some of the problems noted by the IJC Virtual Elimination Task Force report (IJC, 1993) included data gaps in baseline

information, pathways and receptors, lack of multi-media approach, and continued use of single chemical-by-chemical approach.

Table 2. List of federal and Michigan regulations affecting chlorine use.

Federal Regulations
Food, Drug and Cosmetic Act of 1938, as amended
Clean Air Act of 1963, as amended
Occupational Safety and Health Act of 1970, as amended
Insecticide, Fungicide and Rodenticide Act of 1972, as amended
Safe Drinking Water Act of 1974, as amended
Resource Conservation and Recovery Act of 1976, as amended
Clean Water Act of 1977, as amended
Toxic Substances Control Act of 1976, as amended
Hazardous Material Transportation Act of 1978, as amended
Comprehensive Environmental Response, Compensation and Liability Act of 1980, as amended
Emergency Planning and Community Right-to-Know Act of 1986, as amended
Superfund Amendment and Reauthorization Act of 1986, as amended
Pollution Prevention Act of 1990, as amended
Great Lakes Critical Programs Act of 1990, as amended
Michigan Regulations
Water Resources Commission Act (Public Act 245 of 1929, as amended)
Fire Prevention Code (Public Act 207 of 1941, as amended)
Air Pollution Act (Public Act 348 of 1965, as amended)
Mineral Well Act (Public Act 315 of 1969, as amended)
Occupational Safety and Health Act (Public Act 154 of 1974, as amended)
Chlorofluorocarbon Compounds Act (Public Act 384 of 1976)
PCB Compounds (Public Act 60 of 1976, as amended)
Pesticide Control Act (Public Act 171 of 1976, as amended)
Safe Drinking Water Act (Public Act 399 of 1976, as amended)
Public Health Code (Public Act 368 of 1978, as amended)
Solid Waste Management Act (Public Act 641 of 1978, as amended)
Hazardous Waste Management Act (Public Act 64 of 1979, as amended)
The Environmental Response Act (Public Act 307 of 1982, as amended)
Groundwater and Freshwater Protection Act (Public Act 247 of 1993)

The USGAO (1991) focused its review on the issue of whether or not (the then) current federal environmental regulations protected people from compounds which were either known or suspected to have adverse reproductive and developmental effect on humans. A total of 30 compounds, of which ten were chlorinated, were selected to be evaluated. The study concluded that of the 12 federal laws reviewed, only five actually had specific language to regulate reproductive and developmental outcomes; and of those, the regulatory actions by the federal agencies still tended to be based more on cancer and acute toxicity rather than reproductive and developmental concerns.

Given both the above and the subjective nature of Directive #2, a set of general review

criteria were established which would be useful to help ameliorate some of the subjectivity of its evaluation. From the MESB Chlorine Panel's perspective, any evaluation of how well a given law or regulation protects should address the following three concerns: (1) is the regulation designed to provide a reasonable level of protection against the type of harm that would be expected to be caused by the chemical compounds being regulated (in this case, chlorinated compounds), (2) is the regulation being enforced; and (3) is there a mechanism in place to measure the law's effectiveness.

Based on a review of the applicable provisions of the 28 Michigan and federal government regulations (see Appendix II), considerable difference exists among the regulations in terms of their purpose and design. For example, there are only a few regulations which specifically address chlorine or chlorinated compounds. The majority of the laws address the control of a variety of toxic substances of which the majority are non-chlorinated compounds, and of which most would be considered as either persistent toxic substances or highly toxic substances. In addition, the regulations provide for different levels of protection. For instance, most of the regulations are designed to attenuate acute exposure and/or cancer concerns. Many of the laws are technology-driven and only a few are designed for, or at least allow for, such considerations as multi-media evaluations or reproductive and developmental concerns. Virtually no state or federal law considers more than one chemical at a time or takes into consideration the potential for synergistic, antagonistic or catalytic impact of a group of diverse chemical substances which may come out of a pipe or go up a stack and become mixed in the environment. Finally, most of the regulations reviewed are designed either to reduce exposure to humans or to control or remediate *end-of-pipe* or *top-of-stack* pollution and only a few incorporate or encourage pollution prevention methodologies.

With the passage of the federal Pollution Prevention Act of 1990, there has been an impetus for more voluntary and pollution prevention programs at both the federal and state levels. Some of the federal programs which have an impact on chlorinated compounds include the USEPA's 33/50 Program; Lakewide Management Plan Program for Lakes Michigan, Superior and Ontario; Virtual Elimination Pilot Project; and its cooperative efforts with the dry cleaning and printing industries and the Canadian government to further reduce the presence of particularly toxic chlorinated compounds (USEPA, 1993b, 1993c, 1993d; 1993e). At the state level, the Michigan Department of Natural Resources (MDNR), Chrysler, Ford, General Motors and the American Automotive Manufacturers Association have instituted work on an Auto Industry Pollution Prevention Project designed to reduce 65 persistent toxic substances (of which some are chlorinated compounds) in the manufacturing process (USEPA, 1993c). Finally, it is important to note the recent recommendation by the Michigan Environmental Code Commission for Michigan to explicitly enact a pollution prevention law to declare the state's commitment to the national policy of pollution prevention (Cooper *et al*., 1994).

Another issue which has been receiving considerable attention, and one which is not readily addressed in most of the regulations, deals with the much more subtle impacts that chlorinated and non-chlorinated toxic substances may be having on human and non-human biological systems, including, but not limited to: genetic, reproductive, endocrine,

developmental and immune systems, and behavioral irregularities (Giesy, Ludwig and Tillitt, 1994; Holcomb, 1994; Raloff, 1994; Schmidt, 1994; Colborn, vom Saal and Soto, 1993; Guo *et al*., 1993; Peterson, Theobald and Kimmel, 1993; Rier *et al*., 1993; Sharpe and Skakkrbark, 1993; Carlsen *et al*., 1992; Colborn and Clement, 1992; Dawson *et al*., 1990; Jacobson, Jacobson and Humphrey, 1990; 1989; Bowerman *et al*., 1989; Levine *et al*., 1983). To date, literature is beginning to accumulate on these issues; however, the data associated thus far with chlorinated compounds have been limited to relatively few of the known 15,000-plus synthetic and naturally-occurring chlorinated compounds. As more conclusive information becomes available, it is anticipated that these issues will receive greater attention in the regulations.

Given the above, the MESB Chlorine Panel believes that the regulations were reasonably designed to protect against the type of toxicity known to be caused by regulated chlorinated compounds at the time of regulation enactment and/or amendment. However, regulations may not have kept pace with changing technology. Newer or more appropriate testing, monitoring and/or evaluation requirements must be sought and implemented to fully address the concerns currently considered to be of importance in terms of the chlorinated compounds.

The second concern to be evaluated deals with how well the given regulations are enforced. As previously referenced, both the Great Lakes Water Quality Board and the IJC Virtual Elimination Task Force found Canadian and U.S. environmental regulations wanting in this area due to inadequate staff and resources (IJC, 1992a; IJC, 1993). In addition, the USGAO (1991) found a reluctance on the part of some federal regulators to utilize existing regulations addressing reproductive and developmental concerns to their fullest.

During the data-gathering stage of the investigation, the MESB Chlorine Panel received verbal and written testimony from representatives of industry, environmental organizations and state government regarding the overall effectiveness of the state and federal environmental regulations dealing with chlorinated compounds. The responses to this query were predictable and depended on which group was providing the testimony. For example, individuals from the regulated community were more likely to stress how well the laws have been implemented and how aggressively they are being enforced (Alexander, Heydanek and Sterns, 1994; Brown, 1994; Caron, 1994; Donner, 1994; Dow Chemical, 1994; 1993; Smyth 1994a; 1994b), while individuals associated with various environmental organizations were more likely to express concern about the shortcomings of certain state and federal regulations and/or enforcement programs (Eder, 1994; Dempsey, 1994; Vallentyne, 1994). State regulators indicated that the laws were fairly well to well-implemented and enforced, but that inadequate staffing and/or resources limited their agencies' enforcement capabilities (Cleland, 1994; Hurlburt and Saalfeld, 1994; MacKenzie-Taylor, 1994a; Marolf, 1994; Simon, 1994; Wade, 1994).

In addition to the various testimonies, the MESB Chlorine Panel reviewed pertinent environmental data. Improvement in the Great Lakes environment is evidenced in the relatively recent and consistent population increases observed in the bald eagle (Brewer

and McPeek, 1991), osprey (Postupalsky, 1991), merlin (Binford, 1991) and Cooper's hawk (Betz, 1991), and in many of the colonial, fish-eating water birds of the Great Lakes (Giesy, Ludwig and Tillitt 1994, IJC, 1993; Brewer, McPeek and Adams, 1991). The increases have been largely attributed to the banning of DDT (McPeek and Adams 1991) and to the manufacture restriction of the polychlorinated diaromatic hydrocarbons such as PCBs, TCDD and TCDF (Giesy, Ludwig and Tillitt, 1994;). In addition, the concentrations of these compounds have been shown to have decreased in the tissues of birds, their eggs, their food (D'Itri, 1988) and in the Great Lakes environment (Holcomb, 1994; Shantora, 1994; Limno-Tech, Inc., 1993).

At the same time, there are data to indicate that problems still linger in some of the more sensitive colonial fish-eating water birds of the Great Lakes (Tillitt *et al*., 1992; Fox *et al*., 1991; Kubiak, 1989). It has been suggested (Giesy, Ludwig and Tillitt 1994) that many of the problems (for instance, embryo lethality, teratogenesis and other anomalies) which are now being observed in terms of colonial fish-eating birds may be the result of these effects having been masked by the more dramatic effects associated with such chlorinated pesticides as DDT and DDE and the fact that field biologists were not looking for embryonic effects until the 1980s.

Based on the above, the MESB Chlorine Panel believes that sufficient evidence exists to suggest that current regulations have had an impact on reducing some of the more persistent toxic chlorinated substances in the environment. In addition, the Panel contends that no matter how well a law is written, inadequate staffing and resource problems are likely to exist. Based on the available environmental data, and given the human and financial constraints under which the laws must be administered, the Panel believes that the current regulations are being enforced as reasonably as possible. An exception to this conclusion is the Michigan groundwater discharge program (Water Resources Commission Act) which is currently being evaluated by the MDNR (MacKenzie-Taylor, 1994b).

The last concern deals with the existence of mechanisms either specifically called for in the regulations or otherwise available to measure the effectiveness of the regulations. Except for the state's Fish Contaminant Monitoring Program (MDNR, 1993), the MESB Chlorine Panel could not find any consistently used evaluation mechanism for environmental regulations. This represents probably the single largest shortcoming of the Michigan and federal government regulations. It also represents an area where the greatest improvement could be achieved.

Currently, many of the state and federal regulations are technology-driven requiring either BACT, T-BACT, or MACT, and greater and more sensitive detection levels in terms of analytical protocol. Also, many of these regulations provide for only localized impact evaluations of released compounds and do not consider regional and global impacts. In addition, the biotic and abiotic monitoring data collected by the state and federal agencies administering the regulations do not appear to be either centralized or well coordinated, potentially resulting in an incomplete understanding of long term trends occurring in the environment.

According to Gilbertson (1994), the traditional approach to water quality regulations involves the preparation of water quality objectives for specific substances based on experimental determination of the most sensitive endpoint in the most sensitive species, and the analytically determined concentration of the substance in environmental samples or in bioassays. The premise is that if the concentration of the compound is less than the water quality objective, the resource is protected from potential harm caused by the substance. The major drawback to this approach is that if actual injury is occurring, caused by a substance(s) that is undetected and, thus, for which there is no established water quality objective, the situation can remain undetected. A similar concern may be stated for air quality regulations.

The IJC is currently examining a program using bioindicators to monitor changes associated with the prevalence of persistent toxic substances (Fox, 1994). The program would use indicator species to monitor effects as well as exposures to chemical substances. Gilbertson (1994) contends that the monitoring of indicator organisms could provide further verification of the relationship between the injury and the putative causal agent, and that rather than relying on extrapolation from experimentally determined safe levels derived from surrogate species, such a program could provide direct evidence that the resources are no longer being injured. Gilbertson (1994) suggests that indicator organisms could integrate exposures to the persistent toxic substances from multiple sources over a geographic scale relevant to the size of the Great Lakes and thus provide verification(s) regarding the success or failure of the virtual elimination of persistent toxic substances.

Based on the above, the MESB Chlorine Panel believes that there is a need to develop a well-coordinated and consistent monitoring program capable of providing trend data on levels and types of contaminants impacting both the biotic and abiotic environments. At a minimum, the MESB Chlorine Panel believes that a well-designed and scientifically-sound bioindicator monitoring program may have merit as a supplement to current top-of-stack, end-of-pipe air and water quality monitoring programs to help establish current and track future tends in those contaminants which negatively impact on biological systems. Such a program may also serve as a basis from which regulatory initiatives might be evaluated.

Conclusions

The MESB Chlorine Panel concludes that the current body of chlorine and chlorinated compound-related regulations operable in Michigan may be considered reasonably adequate to protect human health, the environment and the Great Lakes but should be (1) periodically reviewed and upgraded in terms of requiring more appropriate monitoring and evaluation requirements consistent with new environmental and human health data regarding chlorinated compounds and their potential substitutes, (2) ensured of sufficient human and financial resources to allow for aggressive and effective enforcement and (3) supplemented with a monitoring program capable of establishing and tracking changing trends in contaminants impacting both the abiotic and biotic environments.

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APPENDIX I

November 18, 1993 Letter from Goovernor John Enlger to the Michigan Environmental Science Board

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STATE OF MICHIGAN
OFFICE OF THE GOVERNOR
LANSING

JOHN ENGLER
GOVERNOR

November 18, 1993

Dr. Lawrence Fischer, Chair
Michigan Environmental Science Board
Department of Management and Budget
P.O. Box 30026
Lansing, Michigan 48909

Dear Dr. Fischer:

Some chlorinated compounds are known to contribute to environmental and human health problems. Given this, the International Joint Commission (IJC) has called for the virtual elimination of the use of chlorine and chlorinated compounds as industrial feedstock. In addition, the IJC has also called for reducing or eliminating other uses of chlorine in the Great Lakes basin. However, the U.S. Environmental Protection Agency and Environment Canada have rejected this recommendation as being too broad.

Within Michigan, numerous industries depend on chlorine chemistry and chlorine feedstock to power their manufacturing and industrial processes. In addition, throughout the state, water treatment operators also rely on chlorine to protect our citizens' water supplies and farmers use chlorinated compounds to enhance their harvests.

Given the potential significance of the IJC recommendations to the state's economy and its ability to adequately protect the health of its citizens, I am requesting that the Michigan Environmental Science Board evaluate the uses of and concerns about chlorine and chlorinated compounds in Michigan in order to provide guidance to policy-makers on these issues.

Specifically, I would like the Board to do the following:

1. Evaluate the scientific basis for the IJC recommendations on chlorine and chlorinated compounds.

2. Based on your evaluation of the IJC recommendations, evaluate whether Michigan's body of regulations affecting the use of chlorine and chlorinated compounds adequately protect our citizens' health, our environment, and our Great Lakes.

I am directing the Office of the Great Lakes, the state departments of Natural Resources, Public Health, and Agriculture to fully cooperate with and support the Board's investigation. I would encourage the Board to also seek assistance in this assignment from federal, state, and municipal governments; the IJC; the academic and scientific communities; and industrial and environmental organizations.

I would appreciate you providing me with your evaluation and recommendations by March 15, 1994. Thank you for your continuing service to the citizens of Michigan.

Sincerely,

John Engler
Governor

JE/wcm

cc: Vernice Davis Anthony, Director, Department of Public Health
Roland Harmes, Director, Department of Natural Resources
Bill Schuette, Director, Department of Agriculture
Keith Harrison, Executive Director, Michigan Environmental Science Board
G. Tracy Mehan, Director, Office of the Great Lakes

APPENDIX II

Description of Federal and Michigan Chlorine-related Regulations

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Appendix II. Description of Federal and Michigan Chlorine-related Regulations.

Table 1 lists the various federal and Michigan laws which have either a direct or indirect impact on the use of chlorine and chlorinated compounds within Michigan. With the exceptions of the federal Toxic Substance Control Act of 1976; Food, Drug and Cosmetic Act of 1938; and Pollution Prevention Act of 1990, and portions of the federal Clean Air Act of 1963; Hazardous Materials Transportation Act of 1978; and Insecticide, Fungicide and Rodenticide Act of 1972, the federal regulations listed are either incorporated in part or entirely by reference into the state's regulatory counterpart. As a consequence, a discussion of only the former six federal regulations is presented. The 14 Michigan regulations and their respective administrative rules are administered by five different state departments: Departments of Agriculture, Labor, Natural Resources, Public Health and State Police (MDA, MDL, MDNR, MDPH and MSP, respectively). Several of the Michigan regulations are jointly administered. A brief summary of the pertinent sections of each of the identified federal and Michigan regulations is presented below.

Federal Food, Drug and Cosmetic Act of 1938, as amended. The federal Food, Drug and Cosmetic Act regulates all new products developed for pharmaceutical use and any additive used in the production of foods. The law is administered by the U.S. Food and Drug Administration (FDA). The FDA requires that manufacturers demonstrate through extensive screening and testing protocols that a new drug or additive is safe and effective before allowing it to be sold. Safety is initially demonstrated in laboratory animals and confirmed throughout clinical trials. Efficacy against the target disease is defined and established during actual human studies conducted according to FDA approved and controlled clinical protocols (McDade, 1994).

The development of a new drug involves toxicological, pharmacological and pharmacokinetic studies in animals before clinical studies can begin. Initial toxicological evaluations focus on acute studies to observe for toxicity following administration of a single dose of a compound. Later studies involve administration of multiple doses over longer periods of time to identify and/or evaluate any adverse effects associated with chronic exposure. Finally, lifetime cancer bioassays and multi-generational studies to assess potential reproductive and developmental effects are usually necessary to complete the toxicological profile of the new substance. Pharmacological studies focus on the mechanism of action as well as on the effects on major body systems and organs. Pharmacokinetic studies are designed to determine how the new substance may be changed or eliminated by the test animals as well as to provide guidance on the duration of action.

Prior to initiating an investigation in humans, an investigational new drug application must be filed with the FDA. The application details the new substance's pharmacological, chemical and physical properties, manufacturing and control methods, clinical development plan (including a specific protocol for the first clinical trial) and a summary of any clinical data acquired abroad.

Generally, three phases are involved in the clinical development of a new drug. In Phase I, safety studies predominate as the toxicity of the new drug in humans is determined. In Phase II, the focus shifts from safety to a determination of efficacy by administering the drug to a limited number of patients with the target disease. In Phase III, more patients are given the new drug in the established dose range and final form. In order to sell the new drug in interstate commerce, a new drug application must be prepared and submitted to the FDA for review. A FDA review team, consisting of physicians, toxicologists, pharmacologists, chemists and database managers, review and consider the reasonableness of the evidence provided by the manufacturer (McDade, 1994).

Water Resources Commission Act (Public Act 245 of 1929, as amended). The Water Resources Commission Act and its associated Administrative Rules provide for the regulation, protection and conservation of the water resources of the state and Great Lakes. The Act is administered by the MDNR.

Table 1. List of federal and Michigan regulations affecting chlorine use.

Federal Regulations
Food, Drug and Cosmetic Act of 1938, as amended
Clean Air Act of 1963, as amended
Occupational Safety and Health Act of 1970, as amended
Insecticide, Fungicide and Rodenticide Act of 1972, as amended
Safe Drinking Water Act of 1974, as amended
Resource Conservation and Recovery Act of 1976, as amended
Clean Water Act of 1977, as amended
Toxic Substances Control Act of 1976, as amended
Hazardous Material Transportation Act of 1978, as amended
Comprehensive Environmental Response, Compensation and Liability Act of 1980, as amended
Emergency Planning and Community Right-to-Know Act of 1986, as amended
Superfund Amendment and Reauthorization Act of 1986, as amended
Pollution Prevention Act of 1990, as amended
Great Lakes Critical Programs Act of 1990, as amended
Michigan Regulations
Water Resources Commission Act (Public Act 245 of 1929, as amended)
Fire Prevention Code (Public Act 207 of 1941, as amended)
Air Pollution Act (Public Act 348 of 1965, as amended)
Mineral Well Act (Public Act 315 of 1969, as amended)
Occupational Safety and Health Act (Public Act 154 of 1974, as amended)
Chlorofluorocarbon Compounds Act (Public Act 384 of 1976)
PCB Compounds (Public Act 60 of 1976, as amended)
Pesticide Control Act (Public Act 171 of 1976, as amended)
Safe Drinking Water Act (Public Act 399 of 1976, as amended)
Public Health Code (Public Act 368 of 1978, as amended)
Solid Waste Management Act (Public Act 641 of 1978, as amended)
Hazardous Waste Management Act (Public Act 64 of 1979, as amended)
The Environmental Response Act (Public Act 307 of 1982, as amended)
Groundwater and Freshwater Protection Act (Public Act 247 of 1993)

Three sections of the Act in particular provide for the prevention and control of water pollution resulting from toxic substances. Section 5 of the Act provides for the establishment of pollution standards for lakes, rivers, streams and other waters in the state; the issuance of permits which will ensure compliance with the state pollution standards; and for taking all appropriate steps to prevent any water pollution which is deemed unreasonable and against the public interest. Section 6 establishes a zero degradation policy for water resources by stating: "*that it shall be unlawful for any person directly or indirectly to discharge into the waters of the state any substance which is or may become injurious to the public health, safety, or welfare; or which is or may become injurious to domestic, commercial, industrial, agricultural, recreational or other uses; or which may become injurious to the value or utility of riparian lands; or may become injurious to livestock, wild animals, birds, fish, aquatic life or plants*." Section 6b requires the filing of annual reports by persons who discharge wastes into state waters containing materials, identified as a "*critical material* " by the MDNR, which are used in or are incidental to their manufacturing process and the associated by-products and waste products.

The Act was amended in 1972 (Public Act 293 of 1972) to authorize the development of a register of critical

materials. The Critical Materials Register (CMR) is a list of chemical compounds of high environmental concern from a water pollution control perspective which may be used, discharged and/or disposed of in the state. The development of the CMR was based on an extensive review of the scientific literature for physical, chemical and toxicological properties of the critical materials. Advice on the establishment and subsequent revisions of the CMR comes from an advisory committee of environmental specialists from academia, industry, government and special interest groups. Chemical compounds reviewed for potential inclusion in the CMR include those with well-recognized adverse effects as well as those materials which may be of specific concern in Michigan. Chemical compounds receiving consideration through this process are evaluated using an extensive hazard assessment process which establishes their level of concern. Those chemical substances posing a high environmental concern are included in the CMR. Every business within the state using critical materials and discharging wastewater must file an annual report on critical materials usage and/or discharge. In recent years, the CMR also has been applied to the state's hazardous waste management program and pollution incident prevention plan program for spill prevention and control. Currently, there are 285 chemical substances and classes, of which 107 are chlorinated, on the CMR. An additional 35 compounds, of which 13 are chlorinated, will be added in 1994 (Hurlburt and Saalfeld, 1994).

The Administrative Rules for the Act contain 22 Parts. Of these, Parts 4, 5, 9 and 22 are the most critical to chlorinated compounds. Part 4 establishes the water quality requirements applicable to the Great Lakes, connecting waters and all other waters of the state. Rule 57 of Part 4 deals with establishing water quality standards for toxic substances. It applies to chemical compounds listed on the CMR, the federal priority pollutants list and any other substances, as determined by MDNR. Water quality standards are in narrative rather than numerical terms. This gives the MDNR the flexibility to address new data as they become available without the time and expense necessary to change rules and regulations. The standard states that toxic substances shall not be present in the waters of the state at levels which are or may become injurious to the public health, safety, or welfare, plant and animal life, or the designated uses of those waters. Allowable levels are established, generally using a chemical-specific approach. The allowable levels are based on either a health-based approach or treatment technology limits. The most conservative approach is taken.

A margin of safety is added to the aquatic maximum allowable concentration, or, in the case of wildlife and human health, the no adverse effect level. These are applied at the edge of the mixing zone after they have reached the receiving waters of the state. For carcinogens, a risk level of no greater than 1:100,000 is established. The guidelines are fairly extensive. There are currently acceptable levels established for 115 substances. Of these, 51 are chlorinated compounds (Hurlburt and Saalfeld, 1994).

Discharges into the state's waterways are regulated through the National Pollution Discharge Elimination System (NPDES) process. Depending on the level of potential discharge, there are a number of permit conditions which may be employed in the development of a NPDES permit. A treatment technology approach, water quality standard based approach, monitoring permit requirements, and/or specific effluent limits requirements might be used, depending on the level of potential discharge. Effluent testing requirements, looking at both acute and chronic effects, may be implemented, and methods such as chemical minimization programs or alternative processes, as are currently being used in the pulp and paper industry with chlorine use in the Kraft mill process. Such programs would reduce the levels of absorbable organic halogens (AOX), dioxins and furans coming from the production process. The MDNR also conducts fish contamination monitoring for bioaccumulative chemical substances, effluent chemicals and sludge characterizations (Hurlburt and Saalfeld, 1994).

Part 5 of the Administrative Rules requires secondary containment in order to prevent the uncontrolled release of chemical substances in case of accidents. This also applies to all salts. Part 5 requires that the MDNR be notified immediately of any spill, and that it receive a report of both the incident and remediation efforts.

Part 9 deals specifically with wastewater reporting and establishes the CMR. It also requires an annual report of the use, discharge and disposal of critical materials by business and industries that do have some type of wastewater discharge. About 4,000 reports are received annually by the MDNR. Table 2 presents

the draft 1991 CMR wastewater reporting and 1993 permit monitoring data for chlorinated and non-chlorinated compounds (Hurlburt, 1994).

Table 2. Draft 1991 CMR wastewater reporting and 1993 monitoring data for chlorinated and non-chlorinated compounds.[1]

Category	Chlorinated Chemicals	Non-Chlorinated Chemicals	Total Chemicals
CMR Chemicals Reported (1991)	81	135	216
CMR Chemicals Used (1991)	.895 billion lbs	5.35 billion lbs	6.24 billion lbs
CMR Chemicals Discharged (1991)	3.93 million lbs	3.78 million lbs	7.71 million lbs
CMR Chemical Residuals (1991)	5.2 million lbs	169.0 million lbs	174.2 million lbs
1993 MI Point Source Discharges[a]	5.42 billion lbs[b]	5.93 billion lbs	11.35 billion lbs[b]

1. From Hurlburt, 1994.
a. Due to recording errors, values should be considered MAXIMUM values only.
b. Includes 2.6 billion pounds of chlorides and chloride salts.

Part 22 of the Administrative Rules is designed to protect the public health and welfare, and to maintain the quality of the groundwater in all usable aquifers for individual, public, industrial and agricultural water supplies. The rules state that the quality of the groundwater in all usable aquifers shall not be degraded from local background groundwater quality as the result of a discharge unless a variance is granted. The rules also state that concentrations of inorganic and organic chemical substances above the concentrations established for them in the National Primary Drinking Water Regulations of the federal Safe Drinking Water Act of 1974 shall not be discharged into the groundwater in usable aquifers, even in those cases where the local background groundwater levels for the chemicals exceed the specified levels. Similar to the rules for surface water, this rule also prohibits any discharge into the groundwater which is, or may become, injurious to the public health, safety, or welfare, or to the domestic, commercial, industrial, agricultural, recreational, or other uses which are being or may be made to the groundwater.

Fire Prevention Code (Public Act 207 of 1941, as amended). The Fire Prevention Code provides regulations primarily for the prevention of fires and the protection of persons and property from exposure to the dangers of fire or explosion. In addition, the Act also provides for the regulation of the storage and transportation of hazardous materials. A hazardous material is defined under the Act to mean an explosive, pyrotechnic, flammable gas, flammable compressed gas, non-flammable compressed gas, flammable liquid, oxidizing material, poisonous gas, poisonous liquid, irritating material, etiologic material, radioactive material, corrosive material or a liquefied petroleum gas. Section 5 of the Act requires that a hazardous material be manufactured, kept or stored, sold, transported, or otherwise handled or disposed of in a manner and by a method as not to constitute a fire hazard or a menace to public peace, health, or safety, or to endanger or cause loss, injury, or damage to persons or property.

In 1990, Michigan adopted the provisions of the federal Hazardous Materials Transportation Act of 1978, as

they relate to the safe packaging and transportation of hazardous materials. Under the federal regulations, chlorine is considered a poison inhalation hazard and requires a poison gas label to be affixed on the cylinder. If the chlorine cylinder weighs more than 10 pounds, a hazardous substance designation would also need to be on the cylinder. In addition, the federal regulations require that an emergency response number be on the shipping label and that information regarding the emergency procedures to be followed for the material being shipped accompany the shipping papers.

Sections 5a, 5b, and 5i provide for state fire marshall inspections of vehicles transporting hazardous materials, certification of firms and vehicles engaged in transporting hazardous materials, and certification of dry cleaning operations using flammable liquids, respectively. Section 5p requires all persons who are employers under the Occupational Safety and Health Act to have, maintain and make available to the local fire chief upon request a list of, and a material safety data sheet for, all hazardous chemical substances which are present in their work place.

Section 21a(1) regulates the sale and use of fire extinguishers. However, with the signing of 1987 Montreal Protocol by the U.S. and 23 other countries and the passage of the 1990 federal Clean Air Act amendments, previously allowed ozone-depleting chlorofluorocarbon, halon, carbon tetrachloride, methyl chloroform and hydrochlorofluorocarbon fire extinguishants are now being phased out. This has resulted in the need to develop non-halon substitute fire extinguishants. In January 1994, the National Fire Protection Association (NFPA) released a new standard (NFPA-2001) on clean agent fire extinguishing systems to replace halon 1301. The eight extinguishants addressed in the standards include FC-3-1-10 (perfluorobutane), HBFC-22B1 (bromodifluoromethane), HCFC Blend A (4.75% - dichlorotrifluoroethane, 82% -chlorodifluoroethane, 9.5% - chlorotetrafluorethane and 3.75% - isopropenyl-l-methylcyclohexene), HCFA-124 (chlorotetrafluoroethane), HFC-125 (pentafluoroethane), HFC-227 (heptafluoropropane), HFC-23 (trifluoromethane) and IG-541 (52% - nitrogen, 40% - argon and 8% - carbon dioxide) (NFPA, 1994). Another substitute recently accepted by the United States Environmental Protection Agency (USEPA), without use restrictions, as an alternative for ozone-depleting halon 1301 is FM-200^{TM} (Great Lakes Chemical Corp., 1993). The Act is administered by the MSP (Clift, 1994).

Air Pollution Act (Public Act 348 of 1965, as amended). The Air Pollution Act provides MDNR the authority to establish standards for ambient air quality and emissions into the air, issue and enforce permits, and to develop a general comprehensive plan for the control or abatement of existing air pollution and for the control or prevention of any new air pollution. Compliance with the federal Clean Air Act of 1963, is required under the Act.

Section 2 of the Act provides definitions for "*air contaminant*" and "*air pollution*". *Air contaminant* means dust, fume, gas, mist, odor, smoke, vapor or any combination thereof. *Air pollution* means the presence in the outdoor atmosphere of air contaminants in quantities, of characteristics and under conditions and circumstances and of a duration which are or can become injurious to human health or welfare, to animal life, to plant life or to property, or which interferes with the enjoyment of life and property in this state and excludes all aspects of employer-employee relationships as to health and safety hazards. Section 16 of the Act indicates that a person who fails to comply with a permit requirement or order is guilty of a misdemeanor and can be fined up to $10,000 plus up to $2,000 per day for a continuing violation.

The Act's Administrative Rules apply to all new or modified sources of toxic air contaminants for which a permit to install is required. There are two basic requirements in the Rules. First, a source must apply best available control technology for toxics (T-BACT). Secondly, after the application of T-BACT, the emissions of the toxic air contaminant cannot result in an ambient impact that exceeds a health-based screening level. The Rules specify methodologies for determining the health-based screening levels for both carcinogenic and non-carcinogenic substances.

Parts 2, 3, 6, 7 and 9 of the Administrative Rules have the greatest impact on chlorinated compounds. Part 2 (Air Use Approval) outlines a two-step permit process that must be completed before any new source of air pollution can be installed, constructed, reconstructed, relocated, altered or operated in the state. In addition,

Part 2 Rules 230, 231, 232 and 240 provide special requirements for construction of new sources of volatile organic compounds, including vinyl chloride and carcinogens; describe the screening methodology for assessing cancer risk; describe the methodology for determining initial threshold screening level; and provide the air quality models that may be used to support or amend the state's air quality implementation plan, respectively.

Part 3 Rules apply to all sources of particulate matter. These Rules specify emission limitations for sources of particulate matter that essentially result in the application of reasonably available control technology. Rules to control the emission of fugitive dust are also included in the Part 3 Rules.

Parts 6 and 7 of the Administrative Rules establish emission limitations and prohibitions for existing and new sources of volatile organic compounds, respectively. Part 6 Rules require reasonable available control technology for the following source categories: gasoline marketing and storage, coating operations, degreasing operations, dry cleaners, petroleum refineries, manufacturing of polystyrene and other organic resins, paint manufacturing, pharmaceutical manufacturing, and synthetic organic chemical manufacturing (leak detection and repair programs only). Part 7 Rules require application of best available control technology for all new sources.

Part 9 Rules provide for miscellaneous emission limitations and prohibitions. Rule 901 specifically prohibits a person to cause or permit the emission of an air contaminant or water vapor in quantities that cause alone or in reaction with other air contaminants either (1) injurious effects to human health or safety, animal life, plant life or significant economic value or property; or (2) unreasonable interference with the comfortable enjoyment of life and property.

Federal Clean Air Act of 1963, as amended. The titles of the federal Clean Air Act which directly impact on the use of chlorine and chlorinated compounds include Title III (National Emission Standards for Hazardous Air Pollutants - HAPs) and Title VI (Stratospheric Ozone and Global Climate Protection) (Taylor, 1994; Simon, 1994).

Title III lists 189 HAPs, which include 58 chlorinated compounds. Emission standards requiring Maximum Achievable Control Technology (MACT) for existing and new source categories which emit the listed compounds are required. Eight years after the MACT standards are established, standards to protect against the residual health and environmental risks must be promulgated, if necessary. Development of the standards would be triggered if more than one source in a MACT category exceeds a maximum individual risk of cancer of 1:1,000,000. The residual risk regulations would be based on the Act's language, which specifies that standards must achieve an ample margin of safety.

Several other sections of Title III could also impact chlorine and chlorinated compounds, including Section 112(r) which requires standards to prevent against the accidental release of toxic chemical compounds as well as 112(c)(6) and 112 (m) which address compounds such as polychlorinated biphenyls (PCBs) and dioxins which could adversely impact water bodies because of their bioaccumulative potential.

Title VI addresses ozone depleting substances such as chlorofluorocarbons (CFCs) and requires the USEPA to list and establish phase-out dates for these compounds. Phase-out dates are similar to those developed at the 1987 Montreal Protocol for Class I (2000, for CFC, halon and carbon tetrachloride, and 2002 for methyl chloroform), but with more stringent interim reductions. Class II (hydrochlorofluorocarbons) substances are to be phased out by 2030.

Titles which may indirectly affect chlorine and chlorinated compounds include Title I (Air Pollution Prevention and Control Non-attainment) and Title V (Operating Permits). Title I requires reductions of volatile organic compounds in ozone non-attainment areas (Taylor, 1994; Simon, 1994).

Mineral Well Act (Public Act 315 of 1969, as amended). The Mineral Well Act regulates wells that are drilled to produce brine, for underground storage, for underground disposal, and wells that are drilled for test

or exploratory purposes. The Act directs that a person shall not cause surface or underground waste in the drilling, development, production, operation or plugging of wells. "*Surface wastes*" is defined by the Act to mean damage to or destruction of surface waters, soils, animal, fish and aquatic life, or surface property from unnecessary seepage or loss incidental to or resulting from drilling equipping, or operating well. The Act defines "*underground waste*" to mean damage or injury to potable water, mineralized water, or other subsurface resources. The Act requires that a permit be obtained prior to drilling a mineral well or converting a mineral well to a new use. The Act also provides for daily fines of $1,000 for violations.

Occupational Safety and Health Act (Public Act 154 of 1974, as amended). The Occupational Safety and Health Act was created to regulate working conditions and to prescribe the duties of employers and employees as to places and conditions of employment. Sections 14a, 14b, and 14k provide requirements for employers, and importers and distributors of hazardous chemical substances to develop an occupational safety and health hazard communication standard, disclose trade secret identity of specific chemical compounds under certain circumstances, and to provide and make readily available to employees material safety data sheets for all hazardous chemical substances in the work place, respectively. Sections 31, 33 and 35 of the Act provide authority to MDPH and the MDL to determine the existence of an imminent danger and require corrective action, issue citations for violations, and assess civil penalties and seek criminal prosecution, respectively.

Four sets of Administrative Rules of the Act have a direct impact on the use of chlorine and chlorinated compounds. The first set, Air Contaminants (R325.51101-R325.51108), regulates employee exposure to 675 substances (121 of which are chlorinated compounds). The second and third sets of rules (Rules 2260 and 2301) regulate employee exposure to vinyl chloride, and the manufacture, processing, repackaging, release, handling and storage of bis-chloromethyl ether, 3,3'-dichlorobenzidine and methyl chloromethyl ether, respectively. The last set of rules incorporates the federal Occupational Safety and Health Act of 1970, regulations on process safety management of 136 highly hazardous chemical compounds (including 36 chlorinated compounds).

Chloroflurocarbon Compounds Act of 1976 (PA 384 of 1976). The Chloroflurocarbon Compounds Act regulates the distribution and sale of certain chlorofluorocarbon compounds and provides for their prohibition in the state. This Act was preempted by the 1990 federal Clean Air Act amendments.

PCB Compounds (Public Act 60 of 1976). The PCB Compounds Act prohibits the manufacture, sale, and use of PCBs, terphenyls and higher polyphenyls. This Act was preempted by the federal Toxic Substance Control Act of 1976. Although residual PCB uses are currently under federal jurisdiction, the state continues to regulate residual PCB contamination due to past use or illegal disposal under the authority of the state's Environmental Response Act (Public Act 307 of 1982).

Federal Toxic Substance Control Act of 1976, as amended. Congress enacted the federal Toxic Substance Control Act of 1976 (TSCA) with the purpose of developing an adequate data base on the type of chemicals produced, the location and volume of chemical production and the risks to health associated with chemical exposure. The Act provides for a regulatory structure to govern the testing, manufacture, processing and distribution of toxic chemicals. The USEPA administers TSCA.

The pre-manufacture notification (PMN) requirement of TSCA requires a manufacturer to notify the USEPA 90 days before producing a new chemical substance. The PMN process includes screening of the new chemical substance through an extensive data base (structure activity relationship) to predict health effects (toxicity) and environmental concerns (persistence, bioaccumulative potential and toxicity) based on the chemical and physical properties of the chemical compound. If the screening process indicates a potential for human or environmental hazard, specific testing may be required before the PMN is approved or the new chemical substance can be manufactured. Manufacturing conditions and end use applications can influence the level of testing required by TSCA. Testing protocols are often supplemented by industrial product stewardship and responsible care/use programs that provide testing beyond federal requirements (McDade, 1994; Bond, 1994).

In addition to being authorized to approve or not approve a new chemical substance for use, the USEPA also has the authority under TSCA to limit or ban chemical production, restrict chemical use, and/or establish labelling, special handling, disposal and quality control requirements, whenever a chemical presently in use is found to pose an unreasonable risk to human health and the environment. TSCA preempted Michigan's PCB Compound Act.

Pesticide Control Act (Public Act 171 of 1976, as amended). The Pesticide Control Act of 1976 and the federal Insecticide, Fungicide and Rodenticide Act of 1972, provide the MDA broad legal authority to regulate pesticides, (chlorinated and non-chlorinated), sold and used in Michigan. The Pesticide Control Act requires: (1) registration of all pesticides used in Michigan, (2) regulation of pesticide distribution, labeling and application practices, (3) licensure of restricted use pesticides dealers, (4) registration, certification or licensing of certain pesticide applicators, and (5) creation of a pesticide advisory committee. Administrative and enforcement procedures including inspection authority, and stop use and cease orders are also provided by the Act. Pesticide use may be suspended or canceled due to unreasonable adverse effects, such as substantial scientific evidence that the use of the pesticide will cause or is likely to cause an unreasonable, serious, chronic hazard to human health or long-term environmental damage which cannot be controlled. Penalties available under the Act include administrative fines of not more than $1,000 per violation or $25,000 for violations occurring with malicious intent. Civil fines may also be imposed up to $5,000 for each offense (Wade, 1994).

There are approximately 550 groups of related pesticide active ingredients in the 45,000 formulated products currently allowed for sale by the USEPA. About 11,000 of these products are registered for sale and use in Michigan. Of the 11,000 pesticides, approximately 450 are classified for restricted (versus general) use and may only be sold by a MDA licensed dealer and used by a MDA certified pesticide applicator. Many of these products contain active and inactive (vehicle, adjuvants) ingredients that are chlorinated (Wade, 1994).

Under the Act, every pesticide product which is distributed, sold, exposed, or offered for sale in the state must be registered with the MDA as either a restricted use or general use pesticide. Restricted use pesticides may be sold only by licensed dealers to state certified pesticide applicators. Non-restricted (general use) pesticides may be sold to the general public. Approximately 450 of the 10,000 pesticide products registered for sale in the state are for restricted use only. Pesticides can be placed on the Restricted Use Pesticide list due to human health, worker protection or environmental protection concerns including groundwater protection. Under a memorandum of understanding, pesticide registration decisions are made by the MDA with review by the MDNR and MDPH.

MDA may refuse to register a pesticide or may cancel or suspend registration if it can be demonstrated based on substantial scientific evidence that the use of the pesticide causes, or is likely to cause if the pesticide is registered, an unreasonable, serious, chronic hazard to human health or long-term environmental damages, which cannot be controlled by designating the pesticide as a restricted use pesticide, by limiting the uses for which a pesticide may be used or registered, or by other changes to the registration or pesticide label.

A recent amendment to the Act (PA 248 of 1993) defines and greatly broadens MDA's authority to require clean-up of groundwater contaminated by pesticides and fertilizers. Section 18a of the amended Act states that if confirmed concentrations of a pesticide exceeds the groundwater resource protection level (Maximum Allowable Concentration Level - MCL, or health advisory level) or a confirmed contaminant has migrated into the groundwater off the property, MDA shall require the person to submit and, if approved by MDA, to implement, a groundwater contamination mitigation plan. Section 18b requires that a groundwater protection rule be promulgated by MDA in the event that a given pesticide has been confirmed in the groundwater at levels exceeding its established groundwater resource response level in at least three different distinct locations, or if the USEPA initiates action against the use of the pesticide because of groundwater concerns.

Federal Insecticide, Fungicide and Rodenticide Act of 1972, as amended. The federal Insecticide,

Fungicide and Rodenticide Act (FIFRA) broadly regulates pesticides in the United States. FIFRA prescribes the necessary testing (toxicology and efficacy) for registration of all potential pesticide products, establishes an enforcement mechanism, and sets forth certification and training requirements for certain pesticide users. FIFRA is administered by the USEPA.

Under FIFRA, the manufacturer of a new pesticide is responsible for completing up to 140 specific tests in order to prepare the data package necessary to receive and/or maintain USEPA product label registration, The exact group of tests required for a given product depends on the pesticide's intended use. Major disciplines and brief overview of some key activities involved in the testing/registration process include: (1) Science and Technology - end-use products, analytical methodology, product chemistry data for the registration package; (2) Residue Chemistry and Metabolism Research - nature and magnitude of residues in plants and animals and residues in food and animal feed; (3) Environmental Fate Research - degradation and biotransformation products, effects on rotational crops and non-target organisms and data for environmental monitoring; (4) Toxicology - acute, chronic, lifetime and multi-generational studies including reproduction, teratology and mutagenicity, avian and aquatic effect, and field monitoring studies; (5) Environmental Modeling - computer simulation data analysis and management, predictions of expected environmental concentrations under various field conditions; and (7) Good Laboratory Practices and Quality Assurance. A typical time period for the process is seven to ten years at an approximate cost range of $35 - $60 million (Wade, 1994, McDade, 1994).

Safe Drinking Water Act (Public Act 399 of 1976, as amended). Under the Safe Drinking Water Act, the MDPH has the authority to regulate public water supplies and suppliers of water. Section 6 of the Act incorporates the MCLs of the federal Safe Drinking Water Act of 1974 for certain inorganic and organic chemical compounds and other contaminants. Section 15 of the Act provides MDPH the authority to inspect public water works and suppliers of water, and to require changes to their operations if deemed necessary to ensure the protection of public health. In addition, MDPH is given the authority to issue emergency orders requiring the public water system to make needed changes if the public water system is determined by MDPH to pose an imminent hazard to the public health. Finally, MDPH may take appropriate action to limit water system expansion or water use from a public water supply until satisfactory improvements are made in the system or operation to provide for a continuous, adequate supply of water meeting the state drinking water standards.

Parts 3, 6, 7, 8, 9, 11, 12, 15, 21, and 25 of the Administrative Rules impact on the use of chlorine and chlorinated compounds. Under Part 3, Rule 303 prohibits disinfection requirements from variance or exemption from a state drinking water standard. Rule 308a identifies as a variance the use of chloramines, chlorine dioxide, improved clarification and movement of the point of chlorination as best technology available for achieving compliance with the MCL for total trihalomethanes. Rule 308b identifies as a variance the use of either granular activated carbon or packed tower aeration or both as best technology for achieving compliance within the MCLs for 36 organic compounds (26 of which are chlorinated compounds).

Part 6 of the Rules establishes MCLs for organic and inorganic chemical compounds, microbiological contaminants and turbidity which were not established under section 6 of the Act. Specifically, Rule 604b establishes drinking water MCLs for 18 volatile organic substances (13 of which are chlorinated compounds). Similarly, Rule 604b establishes MCLs for 19 synthetic organic substances (15 of which are chlorinated compounds). Rule 608 provides for the analytical techniques to be used for determination of residual disinfectant concentrations.

Part 7 of the Rules describes the surveillance, inspection and monitoring requirements. Rules 716, 717, 717a, 719a-719d and 720 provide the requirements for collection and analysis of volatile organic compounds, synthetic organic compounds, Type I public water supplies, volatile organic compounds, total trihalomethane and residual disinfectants, respectively. Rule 732 describes the level of testing required of suppliers of water.

Part 8 (Rule 831) requires the disinfection of new or reconditioned wells or pump installations. Part 10 of the Rules establishes requirements to be met by suppliers of water providing treatment of surface water sources

for public water. Rules 1004 and 1008 describe the requirements for adequate disinfection of such water treatment systems.

Part 11 of the Rules establishes requirements to be met for distribution systems and water storage tanks. Rules 1110 and 1117 describe the requirements for adequate disinfection of water mains and water storage tanks, respectively. Part 12 (Rule 1207) requires disinfection of a water distribution system in the event of an interruption or failure in the source of water supply. Part 15 of the Rules establishes the compliance requirements for operation reports and record keeping.

Part 21 of the Rules describes the requirements for the approval of chemicals, materials, coatings, additives or other substances proposed to be used in the treatment or during the distribution of drinking water, or which are proposed to be used in contact with drinking water prior to, or during, distribution to the customer or user of a public water supply.

Part 25 (Rule 2505) requires water haulers to add chlorine, pursuant to MDPH requirements, when receiving water from a source and upon delivery of the water after hauling. At delivery of the water, a free chlorine residual of 1.0 mg/l is required.

Public Health Code (Public Act 368 of 1978, as amended). Of the 70 different areas addressed in the Public Health Code, two (Parts 125 and 127) are of concern regarding the use of chlorine and chlorinated compounds. Part 125 of the Code addresses swimming areas and the control of swimmers' itch and nuisance aquatic plants. Rules 56-59 and 94-96 of this Part address public swimming pools and provide the requirements for their chemical disinfection (with chlorine or other disinfectants) and testing. Swimming pool water quality standards are based on the maintenance of a given level of free available chlorine (if chlorine is used) or bromine at certain pH levels. The regulation of swimming pools falls under the jurisdiction of MDPH.

Part 125 also addresses the use of chemical treatment of water to control swimmer's itch and nuisance aquatic plants. The permitting of such surface water treatment is under the jurisdiction of the MDNR. Rule 4 of this Part requires all chemical substances to be used for aquatic nuisance control to be registered with both the USEPA and the MDA for the nuisance control activity for which they are proposed. In addition, MDNR may prohibit the use of a given chemical compound if it presents a hazard or potential hazard to public health or the natural resources of the state. Rules 5 and 6 limit the time of the year that certain aquatic herbicides may be applied. Rule 10 requires that the area of treatment be posted.

Part 127 of the Code provides for the regulation of water well installation. Rules 139, 161 and 244 address the use of chlorine. Specifically, Rule 139(5) calls for the water used for drilling purposes to be chlorinated, clear water containing a free chlorine residual at the time of use. Rule 161(1) calls for new, repaired or reconditioned wells or pump installations to be chlorinated so as to ensure a concentration of at least 50 ppm of chlorine is obtained in all parts of the well. A minimum contact period of two hours for the chlorination is required before the well can be pumped to waste and the chlorine solution removed from the distribution system. Rule 244(2) calls for the use of drilling water to be chlorinated for dewatering wells.

There are two uses for chlorine and disinfection products in water safety. The first is in disinfecting water to make it safe, and the second is for disinfecting facilities that come in contact with water prior to use - storage basins, wells, pipelines, reservoirs, etc. Disinfection of water in the U.S. consists of two distinct processes. The purpose of the first process is to satisfy the demand created by the substances in the water that produce oxygen. The second is to maintain a residual in the distribution system so that once the water leaves the treatment plant there is a residual disinfection capability from the point of delivery to the customer tap. The chlorine disinfection process may itself create unwanted by-products, depending on what is already in the water. In that case potassium chromanginate and ozone treatment can be used. There are three ozone plants in Michigan, one in Monroe, one in Bay City, and one being designed in Ann Arbor. In each case, the water source demands a more powerful oxidant. These plants are also intended to reduce the use of free chlorine, which produces more by-products. Each plant will use a mixture of chlorine and ozone, using ozone at the front end, and chlorine on the distribution end. Chlorine use will be reduced by well over 50%, perhaps

as much as 90%, as a result of this process (Cleland, 1994).

Solid Waste Management Act (Public Act 641 of 1978, as amended). The Solid Waste Management Act regulates the disposal of solid waste which may contain limited quantities of chlorinated compounds which do not fall under the auspices of the state's Hazardous Waste Management Act. Examples of wastes which would be regulated under the Act include household hazardous wastes and wastes from conditionally-exempt small quantity hazardous waste generators. The Act regulates solid waste disposal areas through a system of permits and licenses. The Administrative Rules set forth technical standards and operating requirements for solid waste disposal areas. The goals of the Act are to assure safe and effective management of solid wastes and waste minimization. The MDNR tries to achieve the goals of the Act by requiring proper design and operation of solid waste disposal areas, maintaining more restrictive standards for more toxic substances, requiring extensive monitoring protocols to help assure containment and encouraging the reuse and recycling of low hazard waste materials (MacKenzie-Taylor, 1994).

Hazardous Waste Management Act (Public Act 64 of 1979, as amended). The Hazardous Waste Management Act was patterned after the federal Resource Conservation and Recovery Act of 1976, and is intended to provide for *cradle to grave* regulation of hazardous waste. The Act licenses and regulates persons engaged in generating, transporting, treating, storing and disposing of hazardous wastes. Section 4(3) of the Act defines a "*hazardous waste*" to mean a waste or a combination of a waste and other discarded material including solid, liquid, semisolid, or contained gaseous material which, because of its quantity, quality, concentration, or physical, chemical, or infectious characteristics, may cause or significantly contribute to an increase in mortality or an increase in serious illness or serious incapacitating, but reversible, illness or pose a substantial present or potential hazard to human health or the environment if improperly treated, stored, transported, disposed of, or otherwise managed. Section 6 of the Act provides the basic compliance requirements for any person who generates, disposes, stores, treats, or transports hazardous waste in the state.

Section 47 of the Act requires MDNR to take certain actions upon receipt of information that the storage, transportation, treatment or disposal of hazardous waste may present an imminent and substantial hazard to the health of persons or to natural resources, or is endangering or causing damage to public health or the environment. Among the actions available include the issuance of an order requiring the hazard to be eliminated by the owner or operator of the facility or the generator, transporter, or custodian of the waste constituting the hazard; requesting the state Attorney General to commence action to stop the act; and/or revoking the permit or license. Non-compliance with a MDNR order may result in a cease and desist order revoking the operator or transporter license and other appropriate action. Section 48 provides the sanctions for violation of the Act. Violations are misdemeanors, punishable by a fine of up to $25,000 per violation, $25,000 per day for a continuing violation, or imprisonment for not more than one year, or both.

Part 2 of the Administrative Rules identifies the materials that are considered hazardous under the Act. A waste is a hazardous waste under the rules if it meets any of the following criteria: (1) it exhibits any of the characteristics of ignitability, corrosivity, reactivity, extraction procedure toxicity, or severe toxicity; (2) it is a waste listed in Rule 213 or Rule 214 of the Administrative Rules, or that is listed under 40 CFR Part 261, Subpart D; or (3) it is a mixture of a waste and one or more listed hazardous wastes. Part 2 Rules 217-226 lists the chlorinated compounds which are considered a hazardous waste under Michigan and federal regulations.

Parts 3, 4 and 6 of the Administrative Rules establish the compliance requirements for hazardous waste generators, transporters and owner/operators of hazardous treatment, storage and disposal facilities, respectively.

The goals of Michigan's hazardous waste program are to: (1) provide safe and effective management of hazardous waste, (2) encourage the use of best technology, (3) de-emphasize use of land disposal facilities, (4) encourage the use of less toxic substances and (5) promote efficiency and generation of less hazardous wastes. The MDNR tries to achieve the goals of the Act by mandating stringent waste management

standards, enforcing stringent regulations for design and operation of incinerators and landfills, requiring more restrictive standards for more toxic substances, requiring all wastes to be treated prior to land disposal to reduce toxicity and mobility in a landfill setting, requiring that all landfills be designed to provide protection in conjunction with treatment requirements, and requiring extensive monitoring requirements to assure containment (MacKenzie-Taylor, 1994).

Environmental Response Act (Public Act 307 of 1982, as amended). The Environmental Response Act provides a procedure for identifying, ranking - pursuant to risk, and clean-up of environmentally contaminated sites within the state (Section 10). The Act also sets forth the duties and liabilities of owner/operators of the contaminated sites (Section 12). Due to its all encompassing definition of *hazardous substances*, the Act is broad reaching in terms of the hazardous substances which it can regulate (Section 3). The Act is administered by the MDNR.

Parts 5 and 6 of the Administrative Rules provide the response activities (interim response activities, remedial investigation, feasibility study, remedial action plan, operation and maintenance plan and monitoring requirements) to be undertaken at a site of contamination and the selection of a final remedial action plan, respectively.

Part 7 of the Rules provides the compliance criteria requirements for three different levels (Types A, B, and C) of environmental clean-ups that may be approved by the MDNR. A Type A clean-up reduces the concentrations of hazardous substances to levels that do not exceed background or method detection limits. Type A clean-ups generally apply: (1) to spills and situations where contamination is relatively limited, (2) when the proposing party wishes to remove contaminants to non-detectable levels, (3) to contaminants which have risk-based criteria that are below method detection limits, (4) to contaminants for which there are insufficient data available to establish risk-based criteria and (5) to materials which occur naturally in the environment.

A Type B clean-up reduces the concentrations of hazardous substances to levels that do not pose an unacceptable risk on the basis of standardized exposure assumptions and acceptable risk levels. Type B clean-ups generally apply at sites where the desired outcome is to allow the site to be returned to unrestricted use at the completion of the remedial action although an acceptable concentration of contaminant is left in place.

A Type C clean-up is a site-specific clean-up which reduces hazardous substance concentrations to levels that do not pose an unacceptable risk. Type C clean-ups generally apply at the largest and most complex sites, and at sites where the uses of the property will be limited at the completion of the remedial action.

MDNR uses a risk factor of 1:1,000,000 for carcinogens and human life cycle safe concentrations for non-carcinogens. A total of 207 carcinogenic and non-carcinogenic substances are listed as hazardous in the MDNR MERA Operational Memoranda (Howard, 1994; 1993). Of these, 36 carcinogenic and 33 non-carcinogenic chlorinated compounds are listed.

Part 8 Rules describe the numerical risk assessment model used by the MDNR to assess and score an environmentally contaminated site based on the relative present and potential hazards associated with the site (Marolf, 1994).

Groundwater and Freshwater Protection Act (Public Act 247 of 1993). The Groundwater and Freshwater Protection Act, was signed into law on November 22, 1993. The intent of the Act is to reduce risks to the environment and public health by preventing groundwater contamination from pesticides and fertilizers. Among other things, the Act charges MDA to: (1) develop groundwater stewardship practices and a voluntary on-site evaluation system for users of pesticides and nitrogen fertilizers (Section 7), (2) develop a groundwater advisory council to advise the MDA (Section 8), (3) establish regional groundwater stewardship teams to provide education and on-site technical assistance to persons participating in the stewardship program, (4) develop a program to track restricted use pesticides to their county of application (Section 12),

(5) develop, in conjunction with MDNR and MDPH, a groundwater monitoring program for pesticides and fertilizers (Section 13) and (6) administer the Freshwater Protection Fund, created under the amended Act, to help pay for the above programs (Section 16).

Federal Pollution Prevention Act of 1990. The federal Pollution Prevention Act was enacted November 5, 1990. Section 13101(b) of the Act states that "*The Congress hereby declares it to be the national policy of the United States that pollution should be prevented or reduced at the source whenever feasible; pollution that cannot be prevented should be recycled in an environmentally safe manner, whenever feasible; pollution that cannot be prevented or recycled should be treated in an environmentally safe manner whenever feasible; and disposal or other release into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner*." The Act is administered by the USEPA and charges the agency to develop and implement a strategy which will promote a multi-media approach to source reduction. Some of the agency's responsibilities under the Act include: (1) establishment of standard methods of measurement of source reduction; (2) facilitation of the adoption of source reduction techniques by businesses; (3) coordination with other federal agencies generic research and development of techniques and processes which have broad resource reduction applicability; (4) establishment of an advisory panel to advise on way to improve collection and dissemination of data; and (5) identification and recommendation to Congress on ways to eliminate barriers to source reduction including the use of incentives and disincentives. The Act provides for matching grants to states to promote the use of source reduction techniques by businesses, the creation of a source reduction clearing house to collect and disseminate information on source reduction. The Act also calls for all owners and operators of a facility who are required under section 313 of the Superfund Amendments and Reauthorization Act of 1976 to file an annual toxic chemical release report to file a toxic chemical source reduction and recycling report for the preceding calendar year.

In its final report to Governor John Engler, the Michigan Environmental Code Commission (Cooper *et al*., 1994), indicated that pollution prevention represents a fundamental shift in the way the state of Michigan should approach environmental protection. Future environmental programs should be based on the philosophy that waste can be discharged to the air, water or land only after a determination has been made that there is no prudent and feasible alternative to its creation and discharge. Pollution achieved by "*end-of-pipe*" and "*top-of-stack*" regulations can no longer be relied upon as the primary strategies to protect Michigan's environment and human health. Government policies and programs should be changed to emphasize, first and foremost, the prevention of waste generation at the source. The Commission called for Michigan to explicitly enact a law to declare its commitment to the national policy.